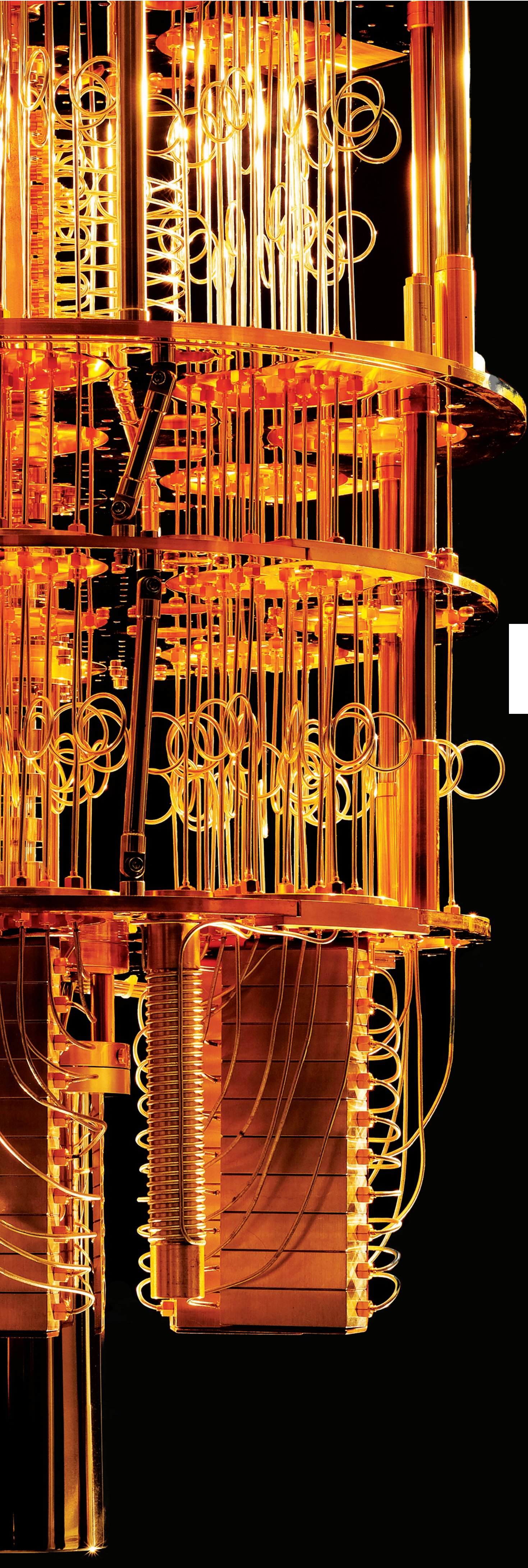

# IMMERSE

2019

# IMMERSE

*IIT Madras Research Magazine*

*7th Edition (2019)*



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# From the Editor's Desk

*Immerse, IIT Madras' Research Magazine is an annually published magazine that seeks to communicate the several developments in the research arena taking place in the laboratories of IIT Madras to the student community and beyond. It is an effort to open the doors of the research world to an audience which is otherwise unaware of how innovation proceeds within four walls and to those familiar, an opportunity to be inspired by fellow-workers.*

*This year's edition features a diverse mix of the latest technologies spanning the minute yet powerful world of quantum mechanics to the large structures that have been successfully created using 3-D printing technology. Small steps can be seen transforming into giant leaps as we transition to a greener world through work yielding successful results in the areas of harnessing solar energy and developing useful products from waste.*

*We would like to extend our thanks to the Director, the Dean of Students, The Fifth Estate and RSD for their continued support for Immerse. We are also extremely grateful to the professors and their students for setting apart their valuable time and welcoming us into their labs to share a piece of their work with us.*

*We invite you dear Reader, to turn the pages to discover for yourself, the wealth of research and interesting insights Immerse has to offer to you in its 7th edition.*

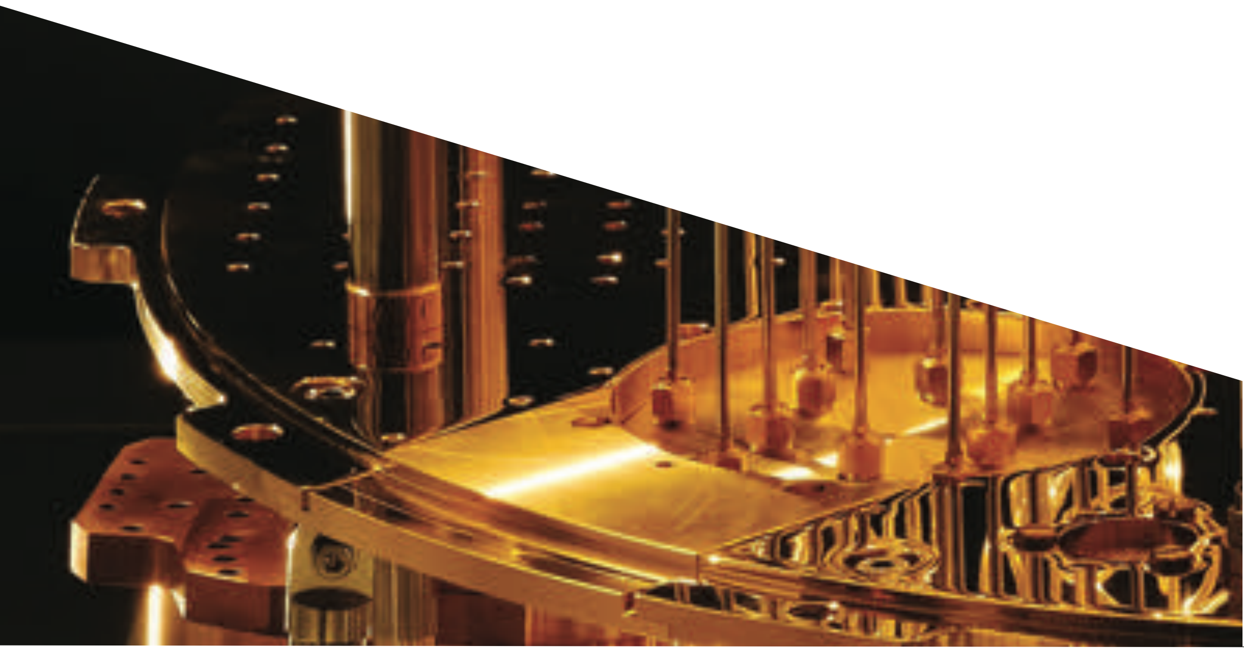
Best wishes,

Ivana, Vidya, Ranjani & Pratyasha
Immerse Editorial Team 2018-2019

# About Cover Page

In case you've been trying to guess what the picture on the cover page is, no, it's not a fancy chandelier. It is a computer. Immerse's cover page this year features the 50-qubit IBM Quantum Computer that was unveiled in November 2017. The construct is kept in a laboratory inside a white casing and connected with pumps to keep it cool, all the way down to 10 milliKelvin. For the device to function efficiently, temperature regulation is an important factor and the pumps and the wiring are designed to that end. The wires carry RF-frequency signals to the quantum chip at the bottom. It is believed that the 50-qubit system could attain quantum supremacy i.e. overpower traditional computing systems or solve the impossible.

''...there is so much 'power' in the quantum world that we are not tapping into'' writes Srilekha. Do read Demystifying the World of Quantum Computing by our writer Srilekha Gandhari to have a taste of the future that quantum computing promises us and the inherent challenges.



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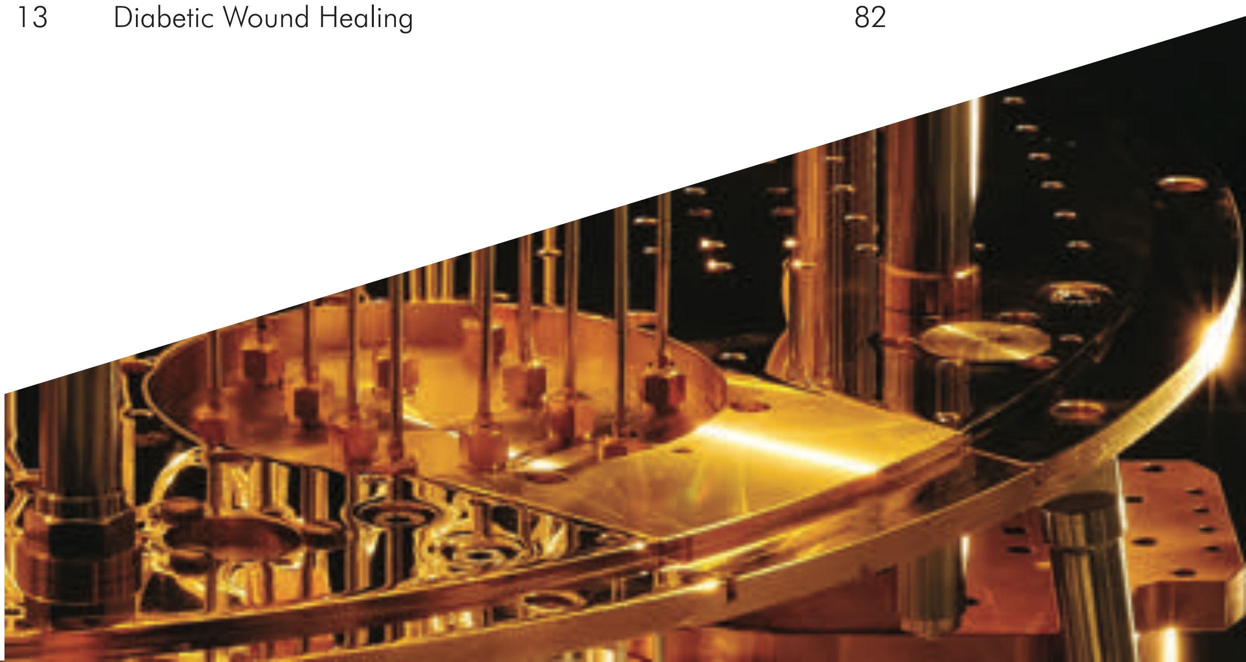


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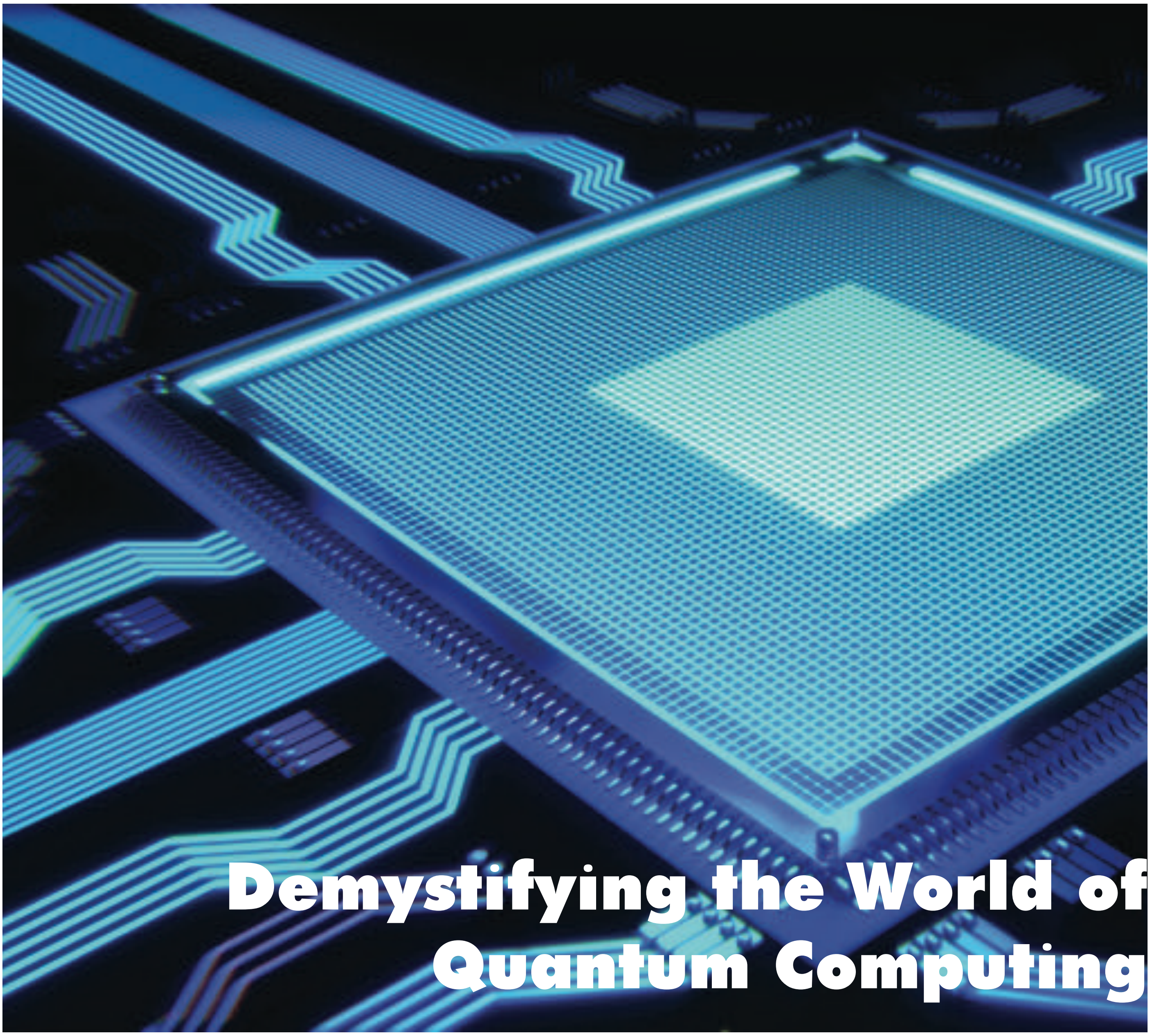
# Research Scholars Day

Research Scholars' Day (RSD), is the premier annual research fest of IIT Madras, aims at celebrating and encouraging budding researchers of the Institute. RSD aims to be a festival, when research scholars can step beyond the confines of their laboratories and witness research in its full splendour while rubbing shoulders with the who's who of industry and academia royalty. RSD is host to a plethora of events ranging from talks by eminent personalities (Lecture Series), technical workshops (Workshop Series), Research Expo and cultural events that bring out the dormant singers and dancers within our scholars. Research Connect, an initiative ideated in 2016-17, is an endeavour to connect industrial research with academia of IIT Madras through interactive sessions, seminars and workshops augment the existing initiatives of the institute to collaborate with the industry. The previous edition of RSD featured the Research Scholar's Portal that provides a window to the outside world into the rich and diverse skill sets and knowledge of the scholars about to complete their theses. The categories featured include biographies, Research information, publications and extracurricular activities.

Previous editions of RSD have hosted personalities like Dr. K. Radhakrishnan, Dr. G Madhavan Nair, Prof. Thanu Padmanabhan and Prof. Jitendranath Goswami, eminent scientists of modern India, Smt. Minal Rohit, Ms. Tanuja Ganu - inspiring women in science and technology, and Prof. M.S. Ananth, Prof. Ashok Jhunjhunwala, visionaries from our very own IIT Madras community.

RSD provides a platform which would push the emerging breed of researchers to rise above and beyond the standard set by pioneers of the yester generations, in empowering the nation through science and technology.



# Demystifying the World of Quantum Computing

Computers have revolutionised the world since their invention over a century ago. We are now at the advent of yet another computing revolution. This new paradigm of computing makes use of quantum mechanics, or the laws that govern matter at very small scales, to achieve feats unimaginable by classical computers. Prof. Prabha Mandayam, from the Department of Physics, guides us through what makes quantum computing so irresistible, while highlighting the major roadblocks encountered on our way towards achieving it. She and her team have been working on Adaptive Quantum Error Correction and are investigating applications of their work in related areas like Condensed Matter Physics.

From major corporates working towards building quantum computers to China launching a satellite for unhackable communication to the US government recently announcing massive funds for Quantum Information Initiatives, Quantum computation is hitting the news everyday. But why is this idea of storing information and performing

**Professor**

Prof. Prabha Mandayam

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computation using quantum states so compelling?

It's not just the rich physics of the field that makes it so fascinating, but also the myriad of applications that follow. It all began with Richard Feynman's famous lecture 'There's plenty of room at the bottom' at Caltech in 1959. He felt that we are not fully exploiting the quantum nature of systems to compute. This creative idea was supplemented by certain computational roadblocks encountered by physicists in the 80's. Classical computers seemed to reach their limits when it came to simulating fundamental physical theories like Quantum Chromodynamics but somehow nature, being inherently quantum, seems to be doing it effortlessly. Soon people realized that there is tremendous 'power' in the quantum world that we are not tapping into.

But how do we harness this potential? Prof. Prabha recalls a saying by Rolf Landauer at IBM; Information is physical. Whether it is stored in the neurons of our brain or in the hard disk of our computer, the nature of information is intimately tied with the physical laws governing the system that it is encoded in. It could be a two-level atom in a cavity, a photon in an optical fiber, an ensemble of nuclear spins like an NMR sample, electron spins in a solid state device. Information is stored in the 'quantum states' of these systems.

Quantum states are unit vectors in a Hilbert space; an abstract linear vector space satisfying certain mathematical conditions. Hence it can be represented by its components along orthogonal vectors in the Hilbert space. A minimum set of orthogonal states needed to represented all the states of the Hilbert space is called a basis for the space.

A 'qubit', or a quantum bit, is a two dimensional quantum system. Consider a two-level atom in a cavity as an example of a qubit. Due to its quantum nature, an arbitrary state of the atom, can be described as a coherent superposition of the excited and ground states. The notation $|0\rangle$ (read 'ket' zero) represents the ground state and $|1\rangle$ represents the excited state. $|0\rangle$ and $|1\rangle$ are orthogonal states and form a basis for the state space. Thus an arbitrary qubit state $|\Psi\rangle$ can be denoted by $\alpha\,|0\rangle+\beta\,|1\rangle$, where $\alpha$ and $\beta$ are complex numbers. The restriction of it being a unit vector implies that $|\alpha|^2+|\beta|^2=1$ and hence $|\Psi\rangle$ can be parametrized as shown in Fig1.

$$
\begin{aligned}
|\psi\rangle &= cos\theta\, e^{i\phi_1}|0\rangle + sin\theta\, e^{i\phi_2}|1\rangle \\
&= e^{i\phi_1}\left(cos\theta\,|0\rangle + sin\theta\, e^{i(\phi_2-\phi_1)}|1\rangle\right)
\end{aligned}
$$

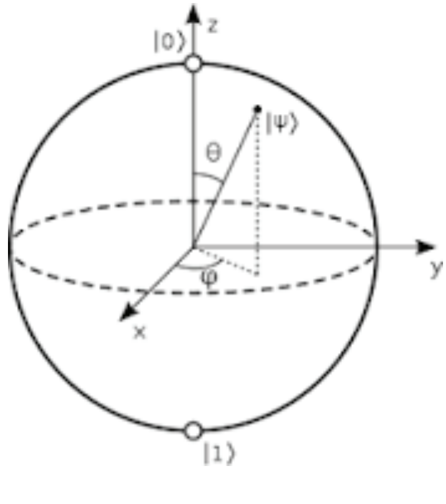



*Fig 1: Bloch Sphere*
*(Image courtesy: Wikipedia_Bloch Sphere)*

Upto a phase factor $\phi_1$, the qubit state can be parameterized just by $\theta$ and $\phi=\phi_2-\phi_1$. This overall phase $\phi_1$ is anyhow irrelevant to us since it cannot be measured experimentally. We are only concerned with the relative phase $\phi$, which is the information carrying factor in a qubit.

Considering $\theta$ and $\phi$ to be the polar and azimuthal angles respectively, all the possible states of this two level system can be visualized on the 'surface' of a sphere of unit radius, called the Bloch sphere. Note that $|0\rangle$ and $|1\rangle$, the only two states that a classical bit can assume are at the poles of the Bloch sphere. The continuum of states that lie between them on the surface, represent the infinity of states that are now accessible to a qubit. Bloch sphere, as Prof. Prabha suggests, is a great way to think of the power acquired in quantum computation as a result of superposition. Moreover, these possibilities grow exponentially with added qubits; an n-qubit system can explore $2^n$ dimensions!

Apart from superposition, quantum states have another trick up their sleeve; Quantum Entanglement. It is this peculiar property that left physicists like Einstein unsettled and earned the title 'spooky action at a distance'. Quantum systems can have correlations beyond that possible in classical systems. Although classical systems can also be correlated like the speed of gas molecules increases with the temperature of the gas, quantum correlations are completely different. Information here is inaccessible at the local level and exists in the correlations. Though the entire entangled system has a definite state, individual parts don't.

Entanglement and superposition are the cornerstones of quantum computation, as a result of which there exist quantum algorithms that display a marked superiority over classical algorithms. For example, the quantum factoring algorithm is known to be exponentially faster than its classical analogue and the quantum search algorithm is quadratically faster.

These quantum algorithms were discovered during the early years of the field. One of the earliest algorithms which showcased the power of superposition in a computing task, namely, the Deutsch-Jozsa algorithm was proposed in 1992, and showed that utilizing quantum states can make the computation exponentially faster. Back in 1983, Charles Bennett and others came up with the idea of teleporting a quantum state using entanglement. Quantum cryptography also goes back to the 80's. However, while these revolutionary ideas are nearly 30 years old, we are lagging far behind in terms of their implementation.

Today, companies like IBM and Rigetti are offering access to cloud-deployed quantum computers (with upto 36 qubits), whereas in academia, most experimental setups have only dozens of qubits that are being manipulated as desired. So, what makes experimental realization of quantum information processing so challenging?

Prof. Prabha explains that one of the biggest bottlenecks we run into is 'decoherence'. It is the irreversible change in the state of a quantum system due to its interaction with the surroundings. The primary goal of Quantum Error Correction (QEC) is to understand the decoherence model. The surface of the Bloch sphere described above the state of an 'ideal' qubit. But in reality, be it nuclear spins or photons, qubits are never isolated -- they are always 'interacting' with their surroundings.

A completely closed quantum system evolves 'unitarily', as governed by the Schrodinger equation. Since states are represented as vectors in a Hilbert space, their transformations are represented as matrices. A unitary evolution, as the name suggests, is a transformation caused by a unitary matrix. Unitary transformations are norm-preserving, i.e. when applied to a pure, single qubit, they map it from one point on the Bloch sphere to another. The most remarkable property of a unitary transformation, however, is that we can always find another unitary transformation to reverse its effect. This arises from the fact that the inverse of a unitary matrix is also a unitary matrix. Being reversible, it doesn't destroy the state, and consequently, the information that the qubit carries.

Decoherence on the other hand, is a non-unitary transformation; it can map a point on the surface of the Bloch sphere to anywhere inside it. Decoherence cannot be reversed perfectly and leads to noise in the system. But why does interaction with the environment have to result in a non-unitary transformation? This is because such an interaction can be interpreted as a 'measurement' performed by the environment.

Unlike a measurement in a classical sense, a quantum measurement completely evades intuition. Measuring a quantum system 'collapses' the state into one of the eigenstates of the measurement operator. It is another way of stating that a quantum state is disturbed as soon as some information about is gained about the state. For example, when the spin of an electron is measured, the result is invariably either along the direction of the magnetic field or opposite to it, even when the initial state is a superposition of the two. Quantum algorithms are always designed keeping this peculiar fact in mind.

At this point one would feel safe to conclude that completely isolating the concerned quantum system from noise, say by cooling the qubits to extremely low temperatures, eliminates decoherence and solves the problem. But unfortunately, this idea has its own shortcomings. Firstly, any effort to isolate them will not do so perfectly. Secondly, we don't want them to be perfectly isolated! We would like to manipulate them at will and extract information when required.

So how does one counter this noise? We deal noise in classical systems also. Thermal noise or radiation can affect classical bits and there is error correction happening all the time in our computers. This classical error correction is achieved by introducing redundancy in the bits. This redundancy helps us in detecting, and eventually correcting the error. Fig.2 shows a simple example where a single bit is encoded into three bits to correct for single bit flips (assuming that the probability of multiple flips is negligible).

Can we emulate this method in quantum error correction? The

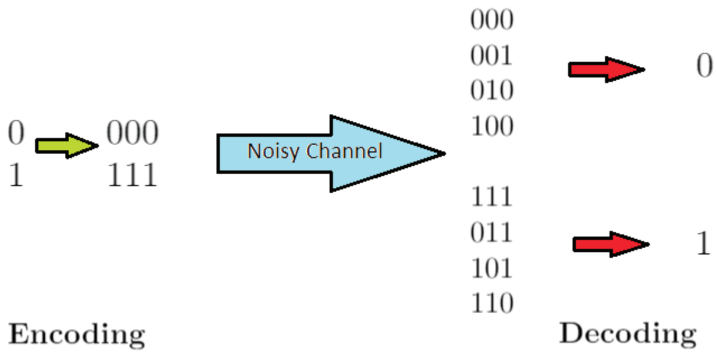



*Fig 2: Classical error correction for bit-flip errors*

answer is a big no : the fact that quantum systems evolve unitarily and are manipulated unitarily means that we cannot 'copy them'. The 'No cloning theorem' formulated in 1982 by William Wootters is a fundamental theorem in quantum mechanics that prohibits exact replication of arbitrary quantum states. These reasons indicate that QEC cannot simply mimic the error correction ideas of its classical counterpart but needs something radically different that exploits the properties unique to quantum systems. Hence QEC is built around creating 'entanglement' between quantum states.

Instead of cloning and adding redundant bits, we initialize new, 'ancilla' qubits selectively either to $|0\rangle$ or $|1\rangle$, and entangle them to the original qubit. Fig.3 illustrates how this technique can be used for QEC of a bit-flip.

This correction protocol is based on the properties of the three-qubit entangled state $\alpha\ |000\rangle+\beta\ |111\rangle$ instead of $\alpha\ |0\rangle+\beta\ |1\beta$. The experimentalist still has no clue what the initial state is, but at the end, has an entangled state containing all the information about it. We cannot factor such a state into individual states of 3 qubits and that is the hallmark of an entangled state. It is a joint state of three qubits and the information is stored in the superposition of this joint state. This is a clever and unique way of overcoming our issue. Moreover, these entangled states are less susceptible to noise.

Now, by performing unitary operations pairwise on these three qubits, we can extract information onto two more ancillary states regarding the nature of the error. With this information, one can implement appropriate corrections

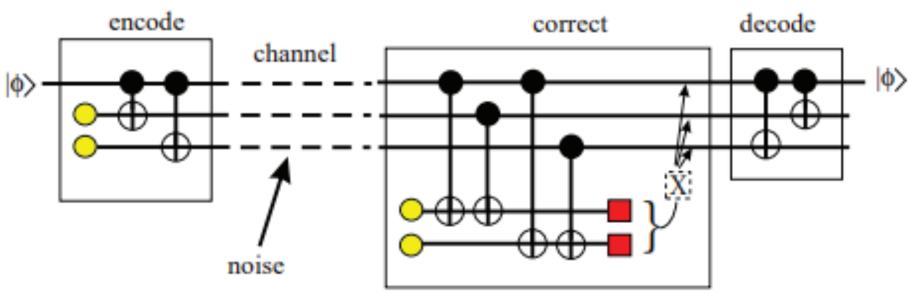



*Fig 3: Correcting for bit flip using ancilla states (Source: https://www2.physics.ox.ac.uk/sites/default/files/ErrorCorrectionSteane06.pdf)*

to get back $\alpha\,|000\rangle+\beta\,|111\rangle$ and can eventually retrieve the original state $\alpha\,|0\rangle+\beta\,|1\rangle$, assuming that only single-qubit errors occurred.

Not only does this QEC protocol help to transmit a $|0\rangle$ or $|1\rangle$ state pretty well, it works just fine with any of the innumerable superpositions of $|0\rangle$ and $|1\rangle$.

To summarize, in a typical QEC protocol, we start by encoding the quantum state by a unitary operation into a QEC 'code'. In the above example, this code was the span of the orthogonal 3-qubit states $|000\rangle$ and $|111\rangle$. Choosing a code is essentially choosing a pair of 'orthogonal' states in a higher dimensional space that play the role of $|0\rangle$ and $|1\rangle\sigma$ (and are hence called logical 0 and logical 1). More formally, it is a subspace of a higher dimensional Hilbert space in which the quantum states are encoded. These encoded states then pass through a noisy channel, after which we extract the information about the error onto some additional ancillary qubits without disturbing the received qubit. This process is called 'Syndrome extraction'. Once the error is known, appropriate unitary transformations are employed to retrieve the original state. Therefore the principal elements of a QEC protocol comprise of the encoding unitary into appropriate 'code' states and the recovery process.

Designing these QEC protocols might have been straightforward and intuitive for a bit-flip error. But there is such richness in the Hilbert space that noise isn't just limited to this one model. Similar to how we can access innumerable quantum states using just a qubit (two-level) system, there are innumerable possibilities for a noise model. This is a striking departure from the classical scenario where a bit can only be either erased or flipped. In the quantum case however, any operation that obeys certain mathematical constraints - called a completely-positive and trace-preserving map - can disturb the state and constitutes noise. Hence an important part of QEC is understanding the noise. Knowing the noise model is essential for us to determine how and to what extent we can correct it.

To parametrize the error matrices, we consider 3 unitary matrices called the Pauli ($\sigma$) matrices which, along with the Identity matrix, form a basis for the space of 2x2 matrices.

This means that any 2x2 matrix can be uniquely represented as $a_x\sigma_x+b_y\sigma_y+c_z\sigma_z$.

A noise process is much more than just an error, it is a probabilistic map. For example, the bit-flip noise meant that a bit might get flipped with a certain probability $p$, or else it remains the same. In other words $\sigma_x$, which is the matrix corresponding to a bit-flip, acts with a probability p and an identity operator $I$, which leaves the bit unchanged, with probability $(1-p)$. This combination

$$I_2=\begin{pmatrix}1&0\\0&1\end{pmatrix},\quad \sigma_x=\begin{pmatrix}0&1\\1&0\end{pmatrix},\quad \sigma_y=\begin{pmatrix}0&-i\\i&0\end{pmatrix},\quad \sigma_z=\begin{pmatrix}1&0\\0&-1\end{pmatrix}$$

*Fig 4: Identity matrix* $I$ *and the Pauli matrices* $\sigma_{x,}$ $\sigma_y$ *and* $\sigma_z$

where the probabilities add up to 1 is a valid noise process and is called a quantum map. Similarly one can have a map for a phase flip ($\sigma_z$) or any other arbitrary combination of the Pauli matrices, subject to the constraint that probabilities add up to 1. These probabilities themselves are time dependent and the chance of an error occurring usually increases with time.

Thus a reasonable approach to error correction would be to figure out the unknown error's components along the σ matrices. Since we know how to correct individually for these elementary errors, we can correct the unknown error.

But it is neither easy nor practical to do so always. Though robust, this approach might not be the optimal solution in every case. There are some quantum systems with well studied noise models where it might be easier to directly obtain the exact noise model from experiments. Finding the components of error involves 'Process Tomography', wherein one takes many initial states and observes what happens to them to reconstruct the process. We basically estimate the probabilities of each component by various trials. This could be a tedious process and also resource intensive.

This is precisely where the notion of 'Adaptive QEC' comes in. Let us understand it with the help of 'Amplitude Damping error', an important example which isn't simply described by one of the σ matrices.

Consider a two-level atom in a cavity. According to quantum mechanics, when prepared in the excited state, this atom can emit a photon and decay back to the ground state. Similarly, when in ground state it can absorb a photon and go to the excited state. So basically, this is an atom interacting with photons, or how physicists would like to call it, a radiation field. This radiation field acts like a bath (surroundings) for the system. One cannot control whether or when a photon will be absorbed or emitted. But what one can model are the probabilities with which they will happen. This system is widely studied in Quantum Optics under the name of 'Jaynes-Cummings' model.

Suppose the atom is prepared in the state $\alpha|g\rangle+\beta|e\rangle$, which is a superposition of the ground state $|g\rangle$, and the excited state $|e\rangle$. It is known that the noise comprises of two kinds of errors which bring the excited state to the ground state. One is the decay, represented by the matrix $E_1$, and the other, known as 'damping', represented by $E_2$. Damping is a quantum effect which reduces the probability of finding the atom in the excited state, as a natural consequence of its interaction with the environment, and is different from $E_1$. So here the noise is a map comprising of the operators $E_1$ and $E_2$, as function of the probability of decay, $\gamma$. According to standard QEC, one would try to decompose this noise in the Pauli basis and correct for the component wise errors. But as explained, that could be a slightly inefficient way of doing it.

$$E_1 = \begin{pmatrix} 0 & \sqrt{\gamma} \\ 0 & 0 \end{pmatrix}, \qquad E_2 = \begin{pmatrix} 1 & 0 \\ 0 & \sqrt{1-\gamma} \end{pmatrix}$$

*Fig 5: The error matrices in Amplitude damping*

Adaptive QEC suggests that we don't break the noise in the Pauli basis but try to correct for it 'as a whole'. But there is a catch here! As we have seen earlier, Pauli matrices are unitary and their effect can be exactly inverted. But neither $E_1$ nor $E_2$ is unitary and therefore if we intend to correct for the noise as a whole, we must tolerate little imperfections in the end result. Accuracy can be improved by using more qubits in the encoding process, but experimentally generating entangled qubits is still a daunting task.

So we employ Adaptive QEC and use the structure of the noise map itself to identify these best codes and recovery process. The $\sigma$ matrices have 'perfect codes'. For example, the single qubit $\sigma_x$ has a three qubit code which guarantees a perfect recovery.

It turns out that the smallest code one needs to 'perfectly' correct any single qubit error is a 5 qubit code. But in Adaptive QEC, we can reduce the resource requirement to 4 qubits, with an accompanying trade off in terms of accuracy. The accuracy of error correction can be quantified using a mathematical expression called 'fidelity' which is a measure of how close two given states are. Higher the fidelity, closer is the error corrected state to the original state.

Prof. Prabha's team worked out the conditions under which Adaptive QEC can be used for a general noise model to result in high fidelity states. Given a noise model, we would want to know what is a 'good' pair of orthogonal states that can be picked as codes. Their team has devised a set of algebraic conditions that can be worked out for a pair of codes to check if they are good enough for a given noise model. They also give you a prescription of a 'pretty good' recovery map.

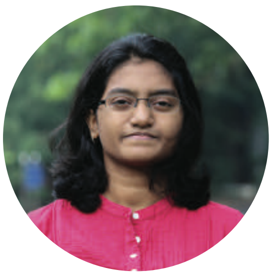
In the case of the $\sigma$ errors, the recovery was a trivial syndrome extraction. But that needn't always be the case. Just like how noise is a process, the recovery is another general quantum process (map) and the best choice comes out of an optimization problem. We have a metric in terms of the fidelity of the final state and the objective function that needs to be maximized. In their work, the team got rid of having to do numerical optimization and presented theoretical prescription to check if a code is good, and suggest a 'pretty good' recovery for a good code.

Prof. Prabha wants to apply this knowledge to actual physical decoherence processes and see how well it works. Akshaya Jayashankar, her PhD student, is working on 'state transfer over spin chains' to check if QEC can help in the transfer of information through longer length spin chains. She is working on reducing this problem down to an error correction problem; to understand the underlying noise model and come up with the best adaptive recovery process. Students in the group are also working on various other topics like directed search for the best codes of a particular length given a noise model and coming up with efficient circuit realizations of the recovery process.

In recent years, connections of QEC to other areas in physics like eigenstate thermalization in many body systems or holographic principle in cosmology have emerged. This compelling theory will be the cornerstone of quantum computation irrespective of the physical architecture on which it is implemented, owing to the fragile nature of quantum states and their high susceptibility to noise. Quantum information and computing still has a long way to go -- from being an exciting physical theory to realising a practical computing device -- and QEC is an indispensable part of that journey.

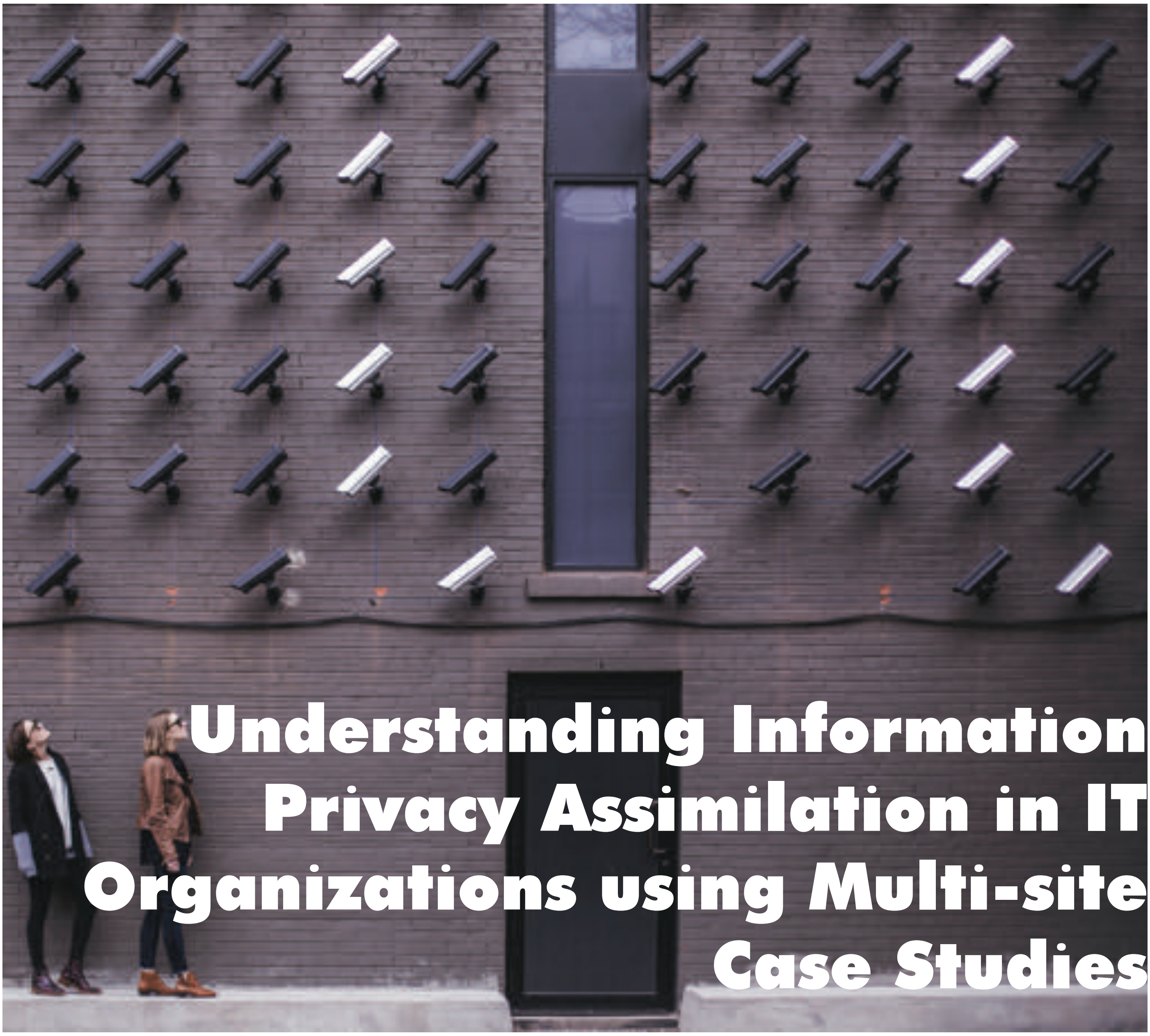
### Professor's Bio

Prof. Prabha Mandayam is an Assistant Professor in the Dept. of Physics at IIT Madras. She obtained her PhD in Physics from the Institute for Quantum Information at Caltech. Her research interests include quantum error correction, quantum cryptography, quantum foundations and quantum information. She has also co-authored the book titled The Functional Analysis of Quantum Information Theory (A Collection of Notes Based on Lectures by Gilles Pisier, K. R. Parthasarathy, Vern Paulsen and Andreas Winter) (Springer, 2015).



### Author's Bio

Srilekha Gandhari is a fourth year undergraduate majoring in Engineering physics. A physics enthusiast who enjoys exploring the vast field, she hopes to pursue research in Quantum Physics. When not immersed in a book or surfing the Internet or scribbling her assignments, she can be found gazing into the sky thinking about satellites and roller coasters.



# Understanding Information Privacy Assimilation in IT Organizations using Multi-site Case Studies

**Professor**

Prof. Saji K. Mathew

**Author**

Shayantan Banerjee

**Editor**

Ranjani Srinivasan

**Why worry about privacy?**

Privacy and how one defines and protects it in today's information-abundant era, is taking a center stage in our country's social and political debate. We live in an internet-driven and mobile device world - a world where we leave our digital footprints everywhere. The list of everyday activities that contributes to this includes healthcare, criminal and legal proceedings, financial transactions, biological traits (genetic information), residence information, geolocation services and search engine data. Companies and big businesses often use this information to profile customers. It is necessary to be worried about information privacy and security because much of the value of a business is the value of data, and there are security issues associated with it.

**Security vs privacy**

In today's digital era, it is very likely that one has come across these words. How does one differentiate privacy from security?

Privacy refers to the rights you have

over your information and how it is being used. Almost all of us click on those "I agree" boxes on the internet on a daily basis (often without reading). Those are the privacy clauses.

Security on the other hand refers to how your personal information is being protected. What software frameworks are in place to protect your information? It's predominantly a technical aspect.

In some sense both privacy and security are related because the two are sometimes used interchangeably in a connected world. But knowing the difference might help you protect yourself online.

Here is an example. Suppose you have gone to a bank to open a savings account. The bank stores your personal information in their own database. Your privacy can be maintained or compromised in one of the three possible ways.

1. The bank stores your information and provides services. Your information is protected.
2. The bank partially releases your personal information to a third-party vendor with whom they have some data sharing agreement. You may have agreed to this while filling up the account opening form. Your data is now in more hands than you think.
3. The bank is hit by a major data breach and all your information has been exposed and sold on the dark web. It's only a matter of time before you are a victim of credit card fraud or some form of identity theft. Both your privacy and security have been lost in this case

Now consider the multitude of sites we go online on a daily basis and share our personal information and then multiply the risk factors (three in the above case) with each of them. Feeling protected yet?

"We don't work on information security, but information privacy", remarked Prof. Saji Mathew of the Dept. Of Management Studies, IIT Madras. He and his hard-working team of researchers have been trying to look at information privacy as a distinct dimension different from information security. Privacy of data, i.e., personally identifiable data of individuals, needs to be protected. Computational tools and algorithms are one way of ensuring that. But this is not the only way; one can have very secure systems but still one's data can be vulnerable. Take the second case of the hypothetical bank as an example. You may think that the bank has very secure systems in place, yet they decide to share your data with a third-party vendor. Of course, you have agreed to that in the disclosure. But what are the policy level implementations that could have better secured your data? This is where information privacy comes into the picture.

It's about policies, practices, rights and systems that are put in place by organizations or communities to ensure that your information is protected. So, it has a much bigger scope. In the recent years, information privacy has been widely debated in our country, especially after the Govt. Of India decided to introduce Aadhaar, a 12-digit unique identity number as a proof of residency for its citizens. The nature and scope of the project made it one of the world's largest data management projects ever undertaken. News about potential data leaks and malpractices followed. The stage for a political spectacle was set.

"At the end of the day all of this is handled by people and people are the most vulnerable links in the chain. So, there are concerns beyond what the computers can offer in terms of security", remarked Prof. Mathew, when asked about our privacy with Aadhaar data.

### The research

Prof Mathew and his team looked at information privacy not on an individual level but on an organizational level. An organization carries a wealth of information about individuals or groups. The main focus of his research was to define information privacy at an organizational level, develop strategies for protecting them and identify the forces responsible for the assimilation of these practices within an organization.

To understand the framework used for this study, we need to consider a widely-used theory in organizational behavior called neo-institutional theory. The following features set it apart from the old institutional theory.

1. **The role of the environment:** Consider a university as an example. It has several individuals co-existing in a particular environment. There are set rules and regulations that define this environment. All the students need to conform to these rules. Here we define university as an organization and education is an institution.
2. **Emphasis on the cognitive basis of human behavior:** The individuals (teachers, educators) follow rules set forth by the government regulatory agencies, more out of conception and rational choice than out of fear or obligation. When it does so, external agencies view the school as a legitimate actor within the higher education field(or the institutional field). The environment then rewards legitimacy with additional support in terms of funding, quality faculty, and interested students.

### The data

The research group studied 18 IT companies from both India and the USA varying across domains such as banking, insurance, healthcare, retail, telecommunications, manufacturing, human resource management, and consulting. They conducted extensive interviews with the decision makers of those companies with a minimum of 10 years of experience in their organizations and who are responsible for information privacy. The qualitative data obtained as a result of these interviews were first transcribed and then analyzed using text analysis tools.

There were more than 25000 words that were transcribed from the interviews and 40 major themes were identified. The responses were quantified using labels such as Y++ (representing more than two-thirds of participants supporting the theme), Y+ (representing more than one-third of participants supporting the theme) and Y (representing two or more participants supporting the theme).

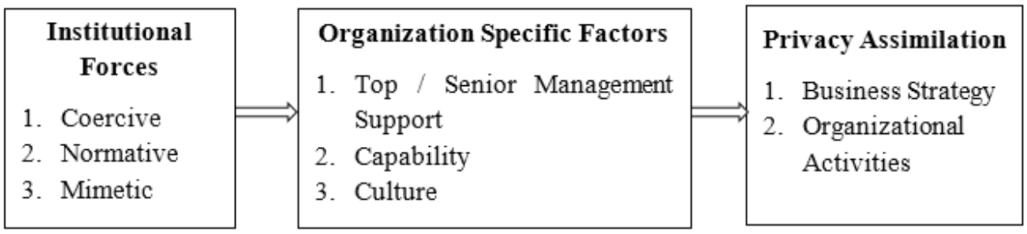



*Fig 1: Proposed framework*

**Analysis**

The themes were identified in the context of privacy in IT organizations. According to the neo-institutional theory, all organizations respond to external forces which are of three types:

1. **Coercive:** In the university example, accreditation agencies require standards of academic and financial quality and force institutions to adapt to maintain their accreditation

2. **Mimetic:** A nearby college may upgrade its campus recreation facilities, leading other surrounding institutions to update their own campus recreation offerings in order to remain competitive.

3. **Normative:** There are certain higher education norms which are mostly "best practices" that influence a university. Examples of this are submission of final of projects or thesis for award of a degree or courses offered at a semester level.

A broad framework was developed to understand the inter-relationships between external and internal forces for privacy assimilation.

The major themes for each of the three external forces were identified and labeled.

| Tag | Themes | Label |
|---|---|---|
| COER1 | Government/regulatory influence | Y++ |
| COER2 | Industry associations' encouragement | Y |
| COER3 | Competitive conditions | Y+ |
| COER4 | Contracts with other businesses | Y |
| COER5 | Customer expectations | Y+ |

*Fig 2: Coercive forces*

| Tag | Themes | Label |
|---|---|---|
| MIM1 | Competitors' successes or failures | Y |
| MIM2 | Perceptions of competitors in industry | Y+ |
| MIM3 | Adoption by successful peer firms | Y |
| MIM4 | Following successful peer firms | Y+ |
| MIM5 | Absence of peer influence | Y+ |

*Fig 3: Normative forces*

The major themes for each of the three internal forces were also identified and labeled.

| Tag | Themes | Label |
|---|---|---|
| NORM1 | Formal education | Y |
| NORM2 | Participating in conferences, forums | Y |
| NORM3 | Journal subscriptions | Y(Limited) |
| NORM4 | Presence of external consultants | Y |
| NORM5 | Dedicated privacy certified employees | Y |

*Fig 4: Mimetic forces*

| Tag | Themes | Label |
|---|---|---|
| SMS1 | Tone at the top | Y |
| SMS2 | Strategy formulation | Y |
| SMS3 | Decision making support | Y |
| SMS4 | Establishing processes and standards | Y+ |
| SMS5 | Providing resources and assigning responsibilities | Y |

*Fig 5: Senior management support*

| Tag | Themes | Label |
|---|---|---|
| CULT1 | Company value and ethics | Y |
| CULT2 | Dynamic / first with competitive actions | Y+ |
| CULT3 | Swift in changing formal rules and policies | Y |
| CULT4 | Workforce in various geographic regions | Y++ |
| CULT5 | Focus on learning, awareness | Y+ |

*Fig 6: Cultural acceptability*

| Tag | Themes | Label |
|---|---|---|
| PCAP1 | Subject matter expertise (SME) | Y |
| PCAP2 | Training opportunities (regular / on-demand basis) | Y++ |
| PCAP3 | Process planning and execution capability | Y++ |
| PCAP4 | Infrastructure capability | Y+ |
| PCAP5 | "Go to teams" for problem solving | Y+ |

*Fig 7: Privacy capability*

The major themes for privacy assimilation were also identified and labeled.

| Tag | Themes | Label |
|---|---|---|
| BST1 | Enhancing company image | Y |
| BST2 | Attracting new customers | Y+ |
| BST3 | Offering new, value added customer services | Y |
| BST4 | Protecting company assets and intellectual property (IP) | Y |
| BST5 | Enhancing effectiveness of data handling | Y |

*Fig 8: Business strategy*

| Tag | Themes | Label |
|---|---|---|
| OAT1 | Proposing and initiating new projects | Y+ |
| OAT2 | Development life cycle phases | Y+ |
| OAT3 | Audit phase | Y+ |
| OAT4 | Third party vendors | Y+ |
| OAT5 | Incident management | Y+ |

*Fig 9: Organizational activities*

These individual themes were then analyzed to understand the interplay between the external and internal forces.

It was found that senior management intervention plays a mediating role between external forces and assimilation of privacy. The strategies formed by the decision makers of a company is then routinized within the organization as practices.

1. Cultural acceptability also turned out to be an important internal force that influences privacy assimilation.
2. Privacy capability was the third major variable in strengthening privacy assimilation in the wake of internal and external forces. Every organization has its own capability to respond to external forces and is mostly determined by the senior management and culture of the organization.
3. Privacy capability can be a differentiating factor between organizations. IT industries should not only concentrate on the regulatory requirements but also on their abilities to respond to privacy.

## Privacy: a right or a commodity?

We often think of privacy as a right that needs to be protected, but it can be used as a commodity too. Just like any other commodities, it has a business value attached to it. This is known as the economic analysis of privacy. Consider Google as an example. The services provided by the search giant is not free of cost although it might seem like that from the surface. It is a trade, just like any other businesses. Google provides users with YouTube, Gmail and Google search, while we surrender our search keys and personal identities - in short, our privacy. It is a business exchange like any other. But at the same time when we find that our data is stored and shared with some external agencies, we feel like we have lost control over our identities.

How much we are willing to pay or accept to protect our privacy forms the basis for the economic analysis of privacy. Similarly, organizations can also evaluate the economic value of their customers' privacy. In the advent of a breach, it becomes a severe loss of reputation for that organization. How does one value that? That is the challenge.

## Challenges going forward

"The major difficulty is in obtaining data", remarked Dr. Mathew when asked about the challenges he faced while doing this analysis. Many organizations have set regulations in place that prevents them to talk to researchers. This in turn hinders the data collection process.

The study described here is largely

empirical. There is a separate quantitative study that is going to be published this year explaining the study in detail.

**To sum up!**

This study tried to look at privacy assimilation in IT industries and what are the forces that influences this assimilation. The interview data was transcribed and major themes were extracted. The analysis showed that industries should be "privacy capable" and this in turn depends upon the strategies formulated by the decision makers and culture of the organization.

## Professor's Bio

Prof. Saji K Mathew is a Professor in the Dept. of Management Studies at IIT Madras. His past experience spans ten years in manufacturing industry, full time PhD research, teaching, academic administrative services and post doctoral research at Emory University, Atlanta (USA). His research interests include: Web Personalization, Information Privacy IT Usage, Adoption, Business Value IT Services, Cloud and Emerging Business Models eGovernment Systems.

## Author's Bio

Shayantan is a research scholar in the Dept. of Biotechnology. He enjoys reading popular science articles and gets inspired by the words and legacy of Carl Sagan and other science communicators. Keeping in mind that "Somewhere, something incredible is waiting to be known", he applies machine learning techniques to understand the principles behind the mutations causing cancer.


# Securities and Insecurities

**Professor**

Prof. Neelesh Upadhye

**Writer**

Rohini J. S.

**Editor**

Ranjani Srinivasan

This article is a two-part analysis on risk management and financial decisions from a mathematical perspective. In this article, we coordinate with Professor Neelesh from the Department of Mathematics to find out more about his work.

Professor Neelesh Upadhye works on probability theory and stochastic processes. Currently, his lab is focusing on five areas of research in probability theory and stochastic processes:

1. Risk theory
2. Recurrent fractals
3. Estimation of stable distributions
4. Probability Approximation
5. Mathematical Finance

### Modelling Finance Distributions

Many of the concepts in theoretical and empirical finance that have developed over the past decades rest upon the assumption that asset returns follow a normal distribution. However, it has been long known that asset returns are not normally distributed. Rather, the empirical observations exhibit fat tails. This heavy-tailed or leptokurtic character of the distribution of price changes has been repeatedly observed in various markets and may be quantitatively measured by the kurtosis in excess of three, a value obtained for the normal distribution. Since stable distributions can accommodate the fat tails and asymmetry, they often offer a very good fit to empirical data. Stable distributions are a class of probability distributions that allow modeling with excess skewness, kurtosis, and heavy tails. They are hence helpful in modeling finance distributions.

The concept was introduced by Paul Irvine in 1920. The stable distribution is an application of the Generalized Central Limit Theorem, which states that the limit of normalized sums of independent identically distributed variables is stable.

There are four important parameters $\alpha$, $\beta$, $\sigma$ and $\delta$.

$\alpha$ is known as the index of stability

$\beta$ is known as the skewness parameter

$\sigma$ is known as the scale parameter

$\delta$ is known as the shift parameter

Traditionally, there have been many parameter estimation methods. The very first method was the quantile estimation technique, developed by Fama and Roll and generalized by McCulloh. This algorithm compromises on accuracy for its high speed. The next method is a regression type developed by Koutrovelus. This algorithm has higher accuracy than the previous one. But high speed is compromised as this iterative procedure is computationally expensive. A modified regressive type method developed by Kogon Williams was developed based on the regression type, removing its iterative property, making the algorithm faster. Yet, the accuracy has not been compromised. A fourth method known as the method of moments developed by Press, is a fairly efficient algorithm, except it is best used for only preliminary estimations. The final method is a maximum likelihood method developed by DuMouchel and Nolan. The accuracy of this algorithm is by far the best. But the high complexity of the algorithm makes it very slow.

The method proposed by Astha and Professor Upadhye, Department of Mathematics, IIT Madras, is a mixture of the regression type, modified regression type and the method of moments algorithms. It has been made computationally efficient by adopting the non-iterative method from the Kogon Williams model. Similar to the maximum likelihood method, it has a low mean squared error.

This method outperforms Kogon Williams method, which is considered to be the best method to fit financial data, in terms of mean squared error and standard deviation. It was applied to IBM data from Yahoo finance for the period of Jan 19, 2012, to March 19, 2018. This data comprised of 1550 daily return values of adjusted closing prices.

When applied to the SBI data, the distance (error) found by using this hybrid method developed in the lab was observed to be far smaller than the Kogon Williams method.

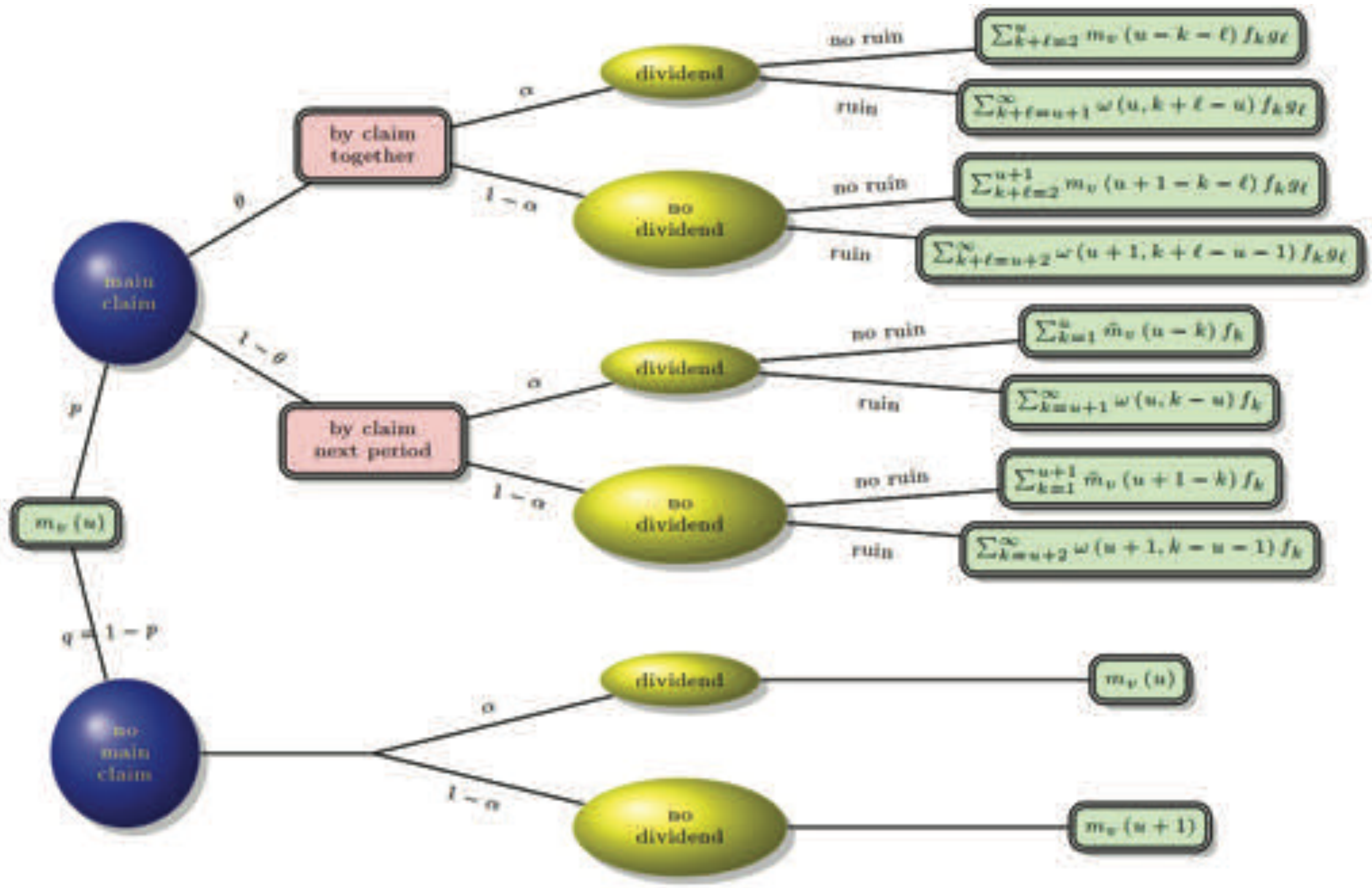



*Fig 1: This figure makes explicit the scenarios of the expected discounted penalty function which is calculated to evaluate the risk of ruin [1] . It was first formulated by Gerbert and Shiu. It entails a number of important quantities in ruin theory, within the framework of the compound binomial aggregate claims with delayed by-claims and randomized dividends payable at a non-negative threshold level.*

## Risk Theory - How Do Insurance Companies Know When They Are Headed For Doom?

Ever wondered how insurance companies decide they are heading towards a dissolution? A company is said to go to ruin when the amount of money they have at a given point of time, called the surplus, is lesser than the total amount of money in claims at that point of time. Insurance companies need to decide this responsibly so that they are able to pay the penalty to all the shareholders of the company.

Another interesting ongoing project in Dr. Neelesh's lab is one on Risk Theory. Aparna is the Ph.D. student who is close to submitting her paper on a generalized compound binomial risk model which includes delayed claims and dividends.

In 1998, Dr. Hans U. Gerber developed a model that dealt with the ruin probability, distribution of deficit at the ruin and the distribution of surplus immediately before the ruin. The assumptions of the standard model is that the company starts off with some balance amount. Then it collects a periodic premium amount from its customers. This is the initial surplus. The claims are modeled using two independent variables, one that decides whether or not there is a claim ($K_i$) and another that models the time at which the claims occur. There is another independent ideal distribution that represents the size of the claim ($X_i$).

Aparna is developing on this model by introducing some tweaks. $K_i$ is modeled as a Bernoulli random variable.

Up to time 'n', we can write an expression for the surplus $S_n$

$$S_n = S_0 + n - \Sigma_i K_i X_i$$

where S0 represents the initial base amount the company has,

N represents the premium collected periodically and the third term representing the total claims that have been made.

This distribution is a classical Binomial model.

More features that were added are the inclusion of by-claims, delayed by-claims and dividends.

By-claims are secondary claims that occur because of the (main) claim. These are usually not a top priority. For example, if a customer has undergone an accident in their car, the health insurance is the main claim and the car insurance is a by-claim. Claiming the insurance to pay the hospital bills is very urgent, whereas claiming the insurance to pay for the damages done to the car is not very urgent. Hence, if the company is not able to dish out enough money for the by-claim, then it does so by the end of the next period. This is called delayed by-claims.

Dividends are amounts of money paid to the stockholders when the surplus crosses a certain threshold. Hence the issuance of dividends is randomized.

Other works done by mathematicians on modeling the ruin probability include the Gerber model with discrete Markov risk models by Yang, discrete renewal risk model with two-sided jumps (where claims can be either positive or negative) by Yang and Zhang.

These models have not been used in the industry so far - despite their inclusions of practical principles, they are still too ideal to be used. We are hopeful that the models are made more practical so they can be put to use by insurance companies.

**Professor's Bio**

"Dr. Neelesh S Upadhye is an associate professor in the Department of Mathematics at IIT Madras. He received his B.Sc. in Mathematics from Wilson College, Mumbai. He pursued an M.Sc. and a Ph.D. in Mathematics from IIT Bombay. Dr Upadhya worked as a Quantitative Researcher at Dolat Investments Ltd., Mumbai for three years before joining IIT Madras as a faculty member. He is an active reviewer of Communications in Statistics: Theory and Methods, Communications in Statistics: Simulation and Computation, Statistics & Probability Letters, Kybernetika, Vietnam Journal of Mathematics, and Bulletin of the Malaysian Mathematical Sciences Society. He is also a member of Editorial Board for the Journal Modern Management Forum.

**Author's Bio**

Rohini is a fourth year undergraduate in the Bioengineering program. Her interests include understanding the biological world through computational systems biology. Her hobbies include playing basketball, playing the violin and singing. She is an avid Carnatic Music enthusiast.

**Editor's Bio**

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# From Seafood Waste to "Biopolymeric" Wealth

**Professor**

Prof.Dhamodharan

**Author**

Sruthi

**Editor**

Vidya Muthulakshmi M

With the rising environmental concerns for disposal of plastic and non-biodegradable waste, it is the need of the hour to synthesis more and more biodegradable forms of material having similar or advanced features. Waste generated industrially and domestically, faces several challenges in collection and segregation into degradable and non-degradable waste, finding proper landfills for degradable waste and recycling non-degradable waste. In this quest of minimizing waste production and adopting effective waste disposal methods, various countries have adopted several measures. For instance, in some countries there are landfills where they are buried, while in some other countries, such as Singapore, the waste is incinerated to produce harmless ash which is released into the oceans in controlled amounts. In India, the seafood waste is treated by any of the following measures: (a) acid-treatment followed by alkaline hydrolysis; (b) buried as solid waste in landfills; or (c) without any pre-processing is dumped into the oceans, causing problems such as pollution, eutrophication and loss of marine life.

Seafood waste comprises of largely crustacean shells of shrimp, prawn, crab, lobster, etc., which contains chitin (15 to 40% by dry weight), calcium carbonate (20 to 50%) and protein (20 to 40%), along with small amount of carotene, fat and minerals other than calcium. When the seafood waste, as a part of waste treatment, is subjected to acid-treatment followed by alkaline hydrolysis, the chitin gets isolated, while forming a "lake" of effluent. Although several biotechnological methods have been adopted for recovering chitin from the crustacean shells, there is difficulty in removing the protein impurity to reach an acceptable level. This residual protein content above permissible limit causes allergies and health problems; thus the chitin directly recovered from seashells is unfit for human consumption. In Japan and Korea, however, the chitin recovered from the shells is legally enabled for human consumption through direct or indirect measures. The seafood waste if left unattended will also pose a threat to the environment. At present, the industries convert it into chitin, in a powdered form by subjecting the shells to acid or alkaline hydrolysis, and use it for certain applications. About 10 to 12 tonnes per annum of chitin is produced every year in India as it has a large sea coast. Thus, some stringent measures need to be adopted to convert this waste into wealth, which is both useful and does end up as additional waste.

From 1990, research on biodegradable polymers began to counter the growing need to produce large volume of commonly used materials that are non-biodegradable, thus minimizing waste production. Out of the naturally occurring biopolymers, the most abundant is cellulose, followed by chitin. Cellulose is not easily available for processing, as it has a very tight structure, for microbes or substances to attack, except when strong reagents such as $CS_2$ are used. Chitin, made up of an N-acetyl glucosamine building block is present in the cell walls of fungi, exoskeletons of crustaceans, insects, and spider; however, it is mainly derived from crustaceans. Chitosan is derived from chitin by deacetylation under controlled conditions. The applications of chitin are limited in comparison to chitosan. Heat treatment cannot produce commercially viable plastic products as it degrades thermally before softening or melting. Its solubility in organic solvents and acid is also an issue. This is so, when it is in amide form; but when it gets converted into amine form, it becomes soluble in organic solvents and acids. So, the reactive groups present in chitosan that aid in solubility are $-NH_2$ groups, apart from $-OH$ groups present in C2, C3 and C6 positions. These reactive groups are instrumental in governing the structural modifications, physicochemical properties and formation of inter- and intra-hydrogen bonds.

Prof. Dhamodharan's enthusiastic and diligent team took this painstaking endeavour to join the task of finding a biodegradable substitute for the non-biodegradable polymers. With a vast sea coast and a thriving fishing industry in India, they turned their research focus on developing sustainable methods of


*Fig 1: Derivatives of Chitin*

treating seafood waste where each one of the valuable ingredients of shell-refinery can be recovered and reused. This required that the structure of the shells, a bio-composite, be understood in some depth in addition to the nature and reactivity of the chemical constituents present. Such an initial exercise enabled the systematic development of methods for the separation the constituents of crustaceans based on their structure, composition and properties.

In the search to put an application to the generated waste materials, Dr Dhamodharan and his team, Dr. Abathodharanan Narayanan, Ravishankar Kartik, and Elanchezhian Sangeetha started developing biodegradable super absorbent polymers (SAPs). In 2014, as part of his PhD work, Dr. Narayanan focused his attention on the field of biopolymers, especially chitosan. He was intrigued and interested in the superabsorbent polymers (also known as SAP). The first SAP was discovered in 1960s by the United States Department of Agriculture (USDA), which developed a resin by grafting acrylonitrile polymer onto starch molecules, thus giving rise to starch-acrylonitrile copolymer. This copolymer absorbed water about 400 times its own weight and did not release water immediately after absorption; hence was named as superabsorbing polymer. In India, Jalsakthi, a super absorbent for agriculture, was developed by NCL, Pune and a partly biodegradable SAP called Pusa hydrogel was developed for agriculture by the Indian Council of Agriculture. These superabsorbent polymers are prepared from synthetic polymers essentially which are from petroleum based source, such as monomeric acrylamide (or acrylate). These are used in diapers, sanitary napkins and packaging materials, and have a well-proven technology established for the past 40 to 50 years due to their long-term stability and water retention capacity. However, they pose a threat to the environment in two ways – they are non-biodegradable and are made from the monomers acrylamide and acrylic acid, which are derived from non-renewable sources, such as petroleum and are toxic in nature. In the polymeric form, after use, they remain in the soil and do not take part in the carbon cycle. For instance, in the case of starch-acrylonitrile copolymer, the starch will biodegrade, while the acrylonitrile part will remain as such in soil.

The team was interested in developing SAPs in such a way as to have a two-fold advantage over the commercially existing SAPs, in being biodegradable and having higher water absorbing capacity. In 2015, they developed SAP using chitosan,

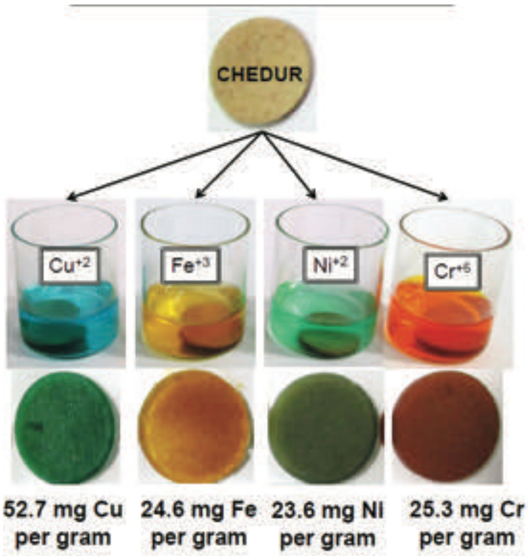



*Fig 2: Adsorption of metal ions by CHEDUR*

EDTA, and urea with the name CHEDUR, having a maximum water absorption capacity of this material was 500 g/g. This biopolymer was suitable for the adsorption of metal ions such as Cu2+, Fe3+, Ni2+ and Cr3+ from aqueous solutions.

Moving forward, they tried to replace EDTA with naturally occurring multifunctional acids, such as citric acid, succinic acid, itaconic acid, so as to adopt green chemistry in their synthesis. Recently, in 2017, they developed an SAP using chitosan, urea and citric acid (CHCAUR) which absorbs 1400 g/g of water, which is eight times more than that absorbed by a regular commercially used diaper material.

The choice of the base material as chitosan for developing biodegradable SAP was due to the favorable and easily tunable physicochemical properties of the biopolymer. The starting material (chitosan) was purchased from Matsyafed, Kochi. The team also does quality check before using any commercially produced material based on well-known parameters such as residual protein content, mineral content, while ignoring the silica content. Some chemical tests are carried out to find the major impurities, protein and mineral content present in the sample. For employing green chemistry in the synthesis of SAP materials, naturally occurring organic acids like citric acid and urea were used. On heating, the substance becomes a gel and then gets converted into a porous sponge-like structure. Soft gels were also produced using this technique with varying color intensity from light to dark colour. Further, stronger gels were also developed by changing the parameters appropriately during synthesis. These variations can be

*Fig 3: SAP Team*

done by changing the parameters. Hence, using chitosan as a backbone of the polymeric waste, a variety of derivatives were produced in the form of biodegradable biopolymers, namely, CHITUR, CHSAUR, among others. Here, 'CH' and 'UR' stand for chitosan and urea, respectively, while 'IT' and 'SA' stand for itaconic acid and succinic acid, respectively.

Biodegradability studies are done using a particular apparatus using ASTM standard 37940 which measures rate of $CO_2$ formed in a soil of unknown composition. Another way is to put the biodegradable polymer in soil and study it over a period of days. First, soil is taken and heated to about 100°C to remove all water content. The remaining organic mass is weighed. This is repeated every two months to find the decrease in the organic mass.

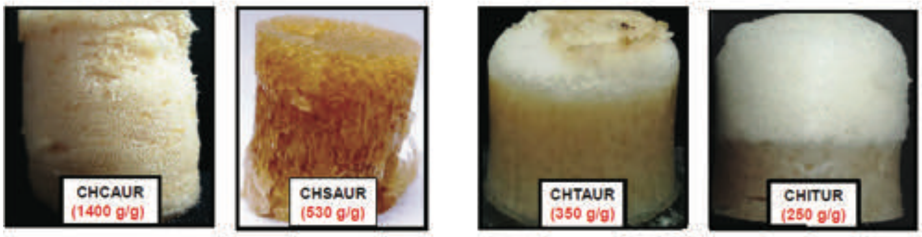



*Fig 5: Other superabsorbent polymers*

*Fig 6: Biodegradability apparatus*

Water absorbance capacity of the SAPs also varies from fresh water to saline water. For saline water, about 250 mL is absorbed, whereas for fresh water about 1.5 L is absorbed. All the derived biodegradable polymers had different water absorbent capacities, which was achieved by tuning the balance between hydrophobic ($-NHCOCH_3$) and hydrophilic ($-OH$ and $-NH_2$) groups. Depending upon the application, different formulations and conditions were controlled to synthesize target specific chitosan-based biopolymers. Another major difference between the parent chitosan and the derived biopolymers is that the parent chitosan is semicrystalline, while the derived biopolymer is more amorphous in nature, thereby exposing all the reactive functional groups. The $-OH$ and $-NH_2$ groups are extensively held together by hydrogen bonds. This hydrogen bond formation and crystalline lattice prevent the chitosan molecule to further undergo reactions or modifications. The amorphous nature of the derived biopolymers exposes the reactive functional groups, especially $-NH_2$ group to enable it to link with electrovalent functional groups, such as polycarboxylic acid and urea. During this synthesis of derived biopolymers, there are three noteworthy aspects – introduction of polycarboxylate ions into the framework, change from crystalline to amorphous nature of the material, and increase in the porosity of the material. The addition of urea causes in situ gas generation because of which the porosity of the material increases. The gases evolved during the process are $NH_3$, which helps in controlling the pH of the reaction, and $CO_2$, which helps

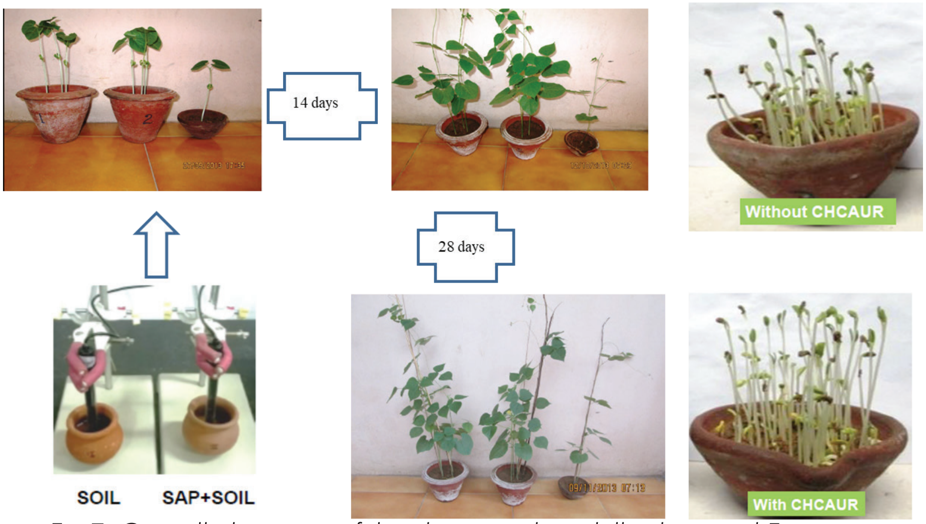



*Fig 7: Controlled reaction of the plant growth in chilly plants and Fenugram*

in increasing the pore formation. The water absorbing capacities of the chitosan derived biopolymers that have been achieved by the group, range from 100 g/g to 1400 g/g. All process control parameters including pH, temperature, molar ratio of the reactant have been optimized to generate the derived forms. A couple of patents have been filed for the design of derived biopolymers based on chitosan (Patent Application No. 201841019768. Date of Entry 26th May 2018) For SAP material a separate patent was filed (patent no. 2505/CHE/2014).

One of the applications for the SAP materials tested by the team is in horticulture, in which they mix the powdered form of the material with the soil used for the growth of chilly and fenugram plants. They found that the water retention capacity of the soil increases to upto 3 days due to the addition of just 4% of SAP material. There is also slow release of micro- and macronutrients which aid in controlled environment plant growth. This is due to the presence of ethylenediaminetetraacetic acid (EDTA), which acts as a chelating agent and binds to a single metal ion like $Cu^{2+}$, $Zn^{2+}$, $Mn^{2+}$ among others. The release of the nutrients follows the degradation of the biopolymer.

This method of producing SAP biodegradable polymers is generating interest among the industries, and a pilot plant was run by renting an industry in Ranipet, Tamil Nadu for 2 days. In this pilot plant, about 10 kg of the SAP material was produced using 2 kL reactor thus successfully taking the production from a confined laboratory scale to broader reaches of industrial scale. For synthesis, hydrothermal method was used with a container having 1000 L capacity and 600 L water to produce 10 kg of the SAP material. Further improvements were carried out to perform the synthesis in open container. Now, the plans to make the product commercially available are currently underway.

Superabsorbents polymers are also used in concrete material, thereby reducing the frequent need to water the material. One of the teams, guided by Prof. Dhamodharan works on an entirely green procedure for conversion of sea shells into chitin, calcium carbonate and protein, and patented it (application no.


*Fig 8: Chitin from seafood waste*

201641030691 filed on May 08, 2017). In one of the methods developed by a team member Ms. Devi, pineapple waste extract (India is largest producer of pineapple in the world) is used to recover chitin and chicken feed in a one-pot reaction. In another method, glycerol, a byproduct of biodiesel as well as soap industry is used to recover chitin, calcium citrate and amino acid residues. The team has also worked on deriving nanochitin from the parent chitin. The patent which deals with deriving nanochitin as a biodegradable reinforcing fibre from shells has also been filed. The process is unique as the fibers produced of nanochitin are extremely strong. However, this synthetic procedure of conversion of chitin to nanochitin unlike that followed for synthesis of SAP material is not entirely green due to the production of some gaseous substances whose composition is yet to be analysed by condensation and other techniques.

Further, greener synthesis of nanocellulose from agricultural waste (rice straw/hay, wood flour, bamboo shredding's, corn leaves, etc.) has also been done by group member Ms. Anju Ramakrishnanan for which patent has been filed (application no. 201841019186 filed on 22nd May 2018).

Chitosan is antibacterial as well, which is useful for biological applications, such as blood clotting applications. Although a haemostatic product is already available as a commercial product, the team is trying to make the product cheaper in India through some modifications. It can absorb erythrocytes and can used for immediate wound treatment for soldiers. Another application is in tissue engineering, in which the SAP material can be used as a biocompatible scaffold, upon which tissue growth can take place. As chitosan is soluble in organic acids, it forms cationic backbone and can be crosslinked with another anionic polymer or colloidal salts, alkali lignin (which is a waste product from the paper industry). A patent has been filed for this ionotropic crosslinking of chitosan (application no. 201841019768 on

26th May 2018). This crosslinking helps in preparing biocompatible antimicrobial hydrogel scaffolds used in tissue engineering.

Future plan of the team is to make some headway into the packaging industry by synthesizing hydrophobic polymers or by utilizing thin film of hydrophobic material to cover the SAP material, while ensuring both the film and the material are biodegradable. Being a new domain for such materials, they are trying to find ways to replace the commercially available polyurethane and styrofoam packaging with biodegradable CHITUR, CHSAUR materials. Further, they are working towards developing greener methods for preparing heat-processable bioplastics using nanofibrillated cellulose and nanocrystalline cellulose from cellulose pulp.

### Professor's Bio

Prof. R. Dhamodharan is a Professor in the Department of Chemistry, IIT Madras. He had also served the Institute in various capacities such as Warden, Tapti, CCW, Warden Central Supplies Unit, Chairman Reverse Osmosis Plants and Head of the Department of Chemistry. He has pronounced expertise in Polymer Science and Engineering, and is passionate towards converting waste to more useful products. Driven by this passion, he was instrumental in setting up reverse osmosis plant near Tapti Hostel, treating grey-water in Krishna hostel through a bed of Australis Phragmates for gardening purposes as well as converting food waste into fertilizer through indigenous efforts.

### Author's Bio

Sruthi is a third year PhD student in Department of Chemistry, and works in the area of materials chemistry. She is a day doer and night thinker, and is always up to something.

# From Bricks to Gypsum, A Shelter for all!

**Professor**

Prof. Devdas Menon

**Writer**

Vidya Muthulakshmi M

**Editor**

Pratyasha Priyadarshini

Everyday morning, we wake up to the bright sun rising outside our windows. Blessed with a roof above our top, we stay protected from scorching heat to raging storms. But even today, affordable homes to everyone remains a dream. Can you imagine owning a super cozy house ready at just Rs. 6 Lakhs in two months? Sounds surprising, right?

Prof. Devdas Menon, Prof. Meher Prasad and their research group at the Department of Civil Engineering started on this venture to bring the dream to reality. They work on enabling rapid affordable mass housing, especially targeting the low and middle income groups. The journey began in 2003, when they were invited to Australia, along with Prof. Aravindan. They witnessed a technology where "Rapidwall" panels were manufactured by an Australian company and realized this had a tremendous potential to be used in our country, where we face housing shortage to a great extent. The Australian company used natural gypsum to construct wall panels at the manufacturing unit and assembled these at the construction site. In the Indian context, there is almost 64 million tonnes of gypsum found as waste from the fertilizer industry. Indeed, to use them for construction stroke two benefits - waste management as well as cost reduction.

So, the team proposed to work on mass housing using Glass Fibre Reinforced Gypsum (GFRG) panels. Conventional building materials such as cement, steel, burnt clay bricks are energy intensive and are high in demand. Alternative materials and speedy delivery stand to be current challenges in the housing industry. GFRG panels are made of gypsum, infilled with reinforced concrete and are proven to be a potential solution. They can be manufactured by any kind of gypsum like flue gas gypsum, mineral gypsum, phosphogypsum or marine gypsum. In India, processed phosphogypsum is used to recycle the waste generated from fertilizer plants.

The panels are cast in three stages. Calcined gypsum with other chemical additives is poured on a special table for casting. Glass fibres are spread evenly on to the mix by a rolling process. Special aluminium plugs are then inserted on top of the finished first layer. There are 20 mm gaps in between. This forms hollow cavities in the panel. Secondly, pouring of the mix is done with cut glass fibre, and pressed down firmly. The first layer is repeated in the third stage to complete the top layer of the panel. Setting takes about 25 minutes and then the plugs are withdrawn. The panel is then taken for drying, where hot air is circulated in a chamber evenly for 19 minutes. These panels are prefabricated to a size of 12 m length, 3 m height and 124 mm overall thickness with a weight of 44 kg/m2. They are load bearing structures, where the walls go all the way to the foundation. Fig. 1 shows the panel elevation and Fig. 2 shows a typical cross section of the panel.

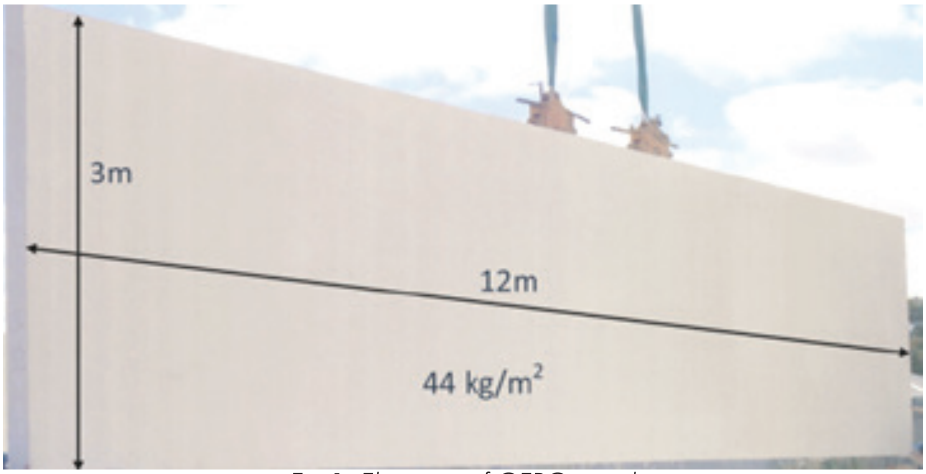



*Fig 1: Elevation of GFRG panel*

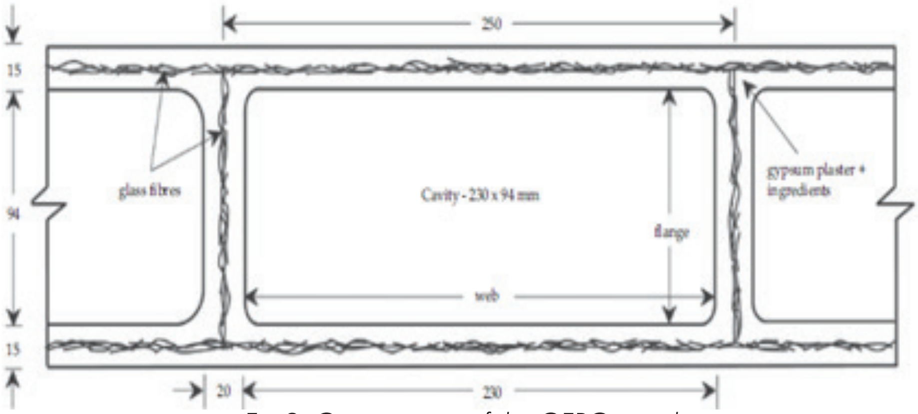



*Fig 2: Cross section of the GFRG panel*

The United Nations Framework on Climate change has confirmed GFRG as a 'green' building material. The research studies on these panels have been carried out in Australia, Hong Kong, China and Malaysia. Their studies so far suggest that panels can only be constructed horizontally, subjected to gravity only. For over 10 years, the team at IIT Madras have carried out theoretical and experimental studies to extend the application of the product to entire building system, including floors, roofs and staircases. Four

PhD scholars have contributed to the development of this technology since 2004. Prof. Devdas states that in contrast to the Australians who have used the panels as only walls, we can also use them as floors when properly designed and reinforced.

So, how do these panels magically become a house to live in? There is a sequence of events. These panels are first fabricated off-site and brought to the construction site for assembly. Prior planning of the architecture of the house plays a major role for efficient construction. The custom sizes in accordance to required plan of the building have to be duly cut from the original size 12m x 3m. To catch up on efficiency, the optimum custom sizes are to be in such a way as to minimize wastage while cutting. Further, a sequence chart is made for on-site work with time schedule. Ensuring the availability of all the materials is also very important.

The building system as a whole comprises of vertical walls and horizontal slabs, without beams and columns. Selected cavities are filled with low-grade concrete and reinforced with minimal steel. For two to three storey buildings, every third cavity is reinforced with an 8mm diameter bar. For high rise buildings, typically all cavities are infilled and reinforced suitably, with one or two bars in each cavity. This provides the desired strength which is essential in external walls under wind loading. In contrast, the same slab when placed horizontally as a floor, a 50mm thick concrete screed is placed at the top along with the reinforcement at every third cavity as shown in Fig. 3.

The screed, provides a diaphragm action to the system under loads that are parallel to the ground like wind and earthquakes, called the lateral loading. Diaphragm element in a system transmits these lateral loads to the vertical elements. A triangular reinforcement cage is inserted at the cavity location as shown in Fig. 4. These beams along with the screed act as series of T beams, spanning upto 5m.

These specifications on the location of the reinforcement in the panels and the cutting drawings have to be explicitly detailed. The openings required for doors and windows are cut priorly off site. If this planning is not done, cost and time would be compromised. The detailed drawings are sent to the manufacturer, who

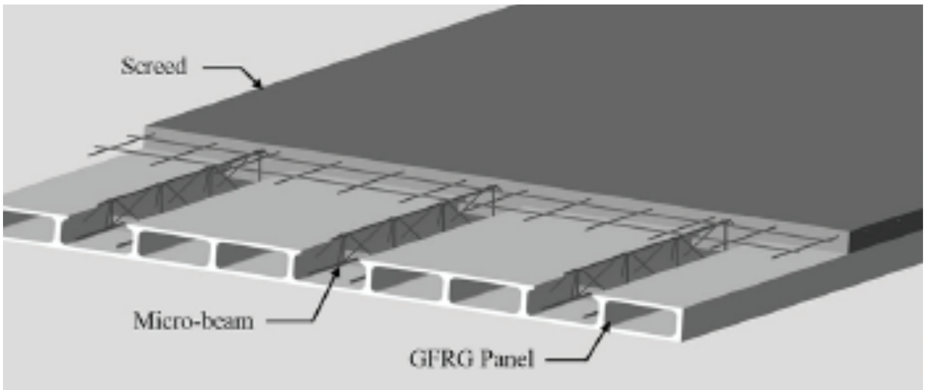



*Fig 3: GFRG floor slab*

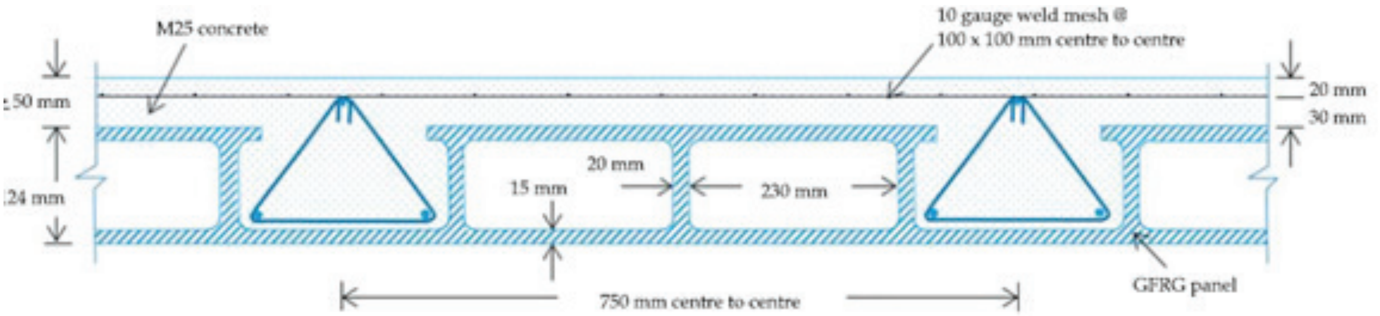



*Fig 4: Reinforcement of the GFRG panels*


*Fig 5: Panels held by stillage and transported via trucks to the construction site*

cuts them accordingly by computer aided technologies. The panels are currently manufactured in India at FRBL, a unit of the Fertilizers and Chemicals Travancore Ltd, Kochi to fixed dimensions with hollow cavities. The panels are then stacked in stillages, and transported to the construction site in trucks. Stillages hold the panels intact during transit as shown in Fig. 5.

On site, strip footings, which are long strips that support the entire wall, are provided for the buildings on soil, for adequate load bearing capacity. Fly-ash block masonry is rested upon the strip footings like conventional foundations. Reinforced concrete plinth beams are provided around the foundation below the walls.This takes the load of the wall that is above it. Starter bars are anchored to these beams at a location to match the points where the cavity reinforcement is done in the panel. A damp proof course (DPC) is applied to the plinth beam as the glass fibers in the GFRG panels can absorb water which can lead to capillary suction. The architect and the project manager has to ensure that the starter bars are perfectly positioned, and the top surface is horizontal. This step is crucial because the panels are pre-fabricated and they cannot be altered. Then the foundation is ready for the superstructure.The foundation process can be seen as in Fig. 6.

*6(a)*

*6(b)*

*6(c)*

*6(d)*

*Fig. 6: Foundation of the structure*

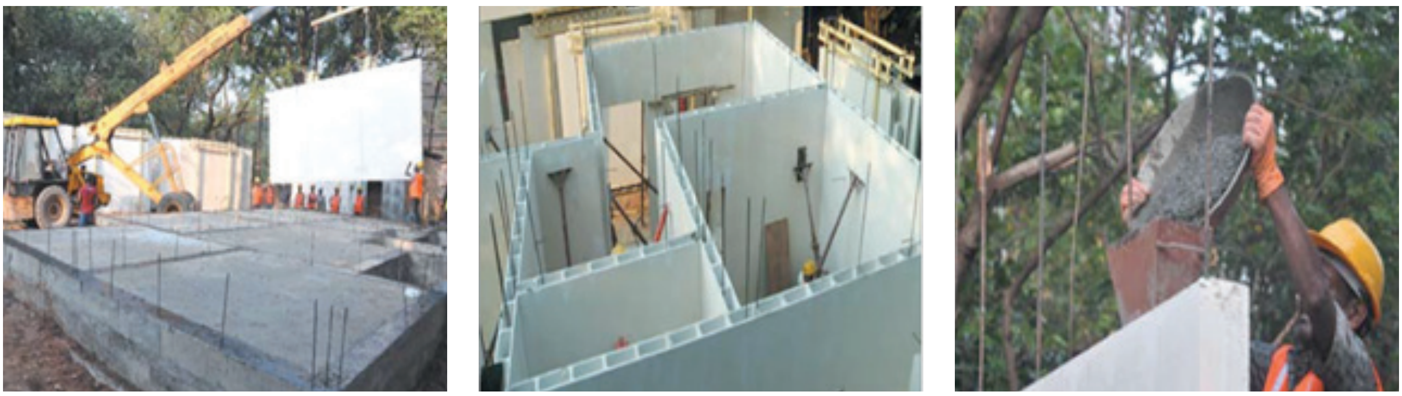
*6(a): Fly ash block masonry; 6(b): Reinforcement laid for plinth beam; 6(c): Waterproofing of Foundation; 6(d): Foundation with starter bars in position*

The wall panels are lifted and erected on to the foundation which has the network of reinforced concrete plinth beams. Once erected, the vertical and horizontal levels are checked and adjustments are made by labour and crane. The reinforcement is then made in the appropriate cavities and tied to the starter bars which were placed in the foundation. The joint between the panel and the plinth beam is sealed by a water proofing chemical, so that there is no leakage of the concrete slurry. Then the infill of concrete is done at every third cavity. The cavities in the panel are filled at an interval of 2 hours, four times. The adjacent cavities near doors and windows are also filled. All joints are filled with concrete and reinforced with steel. Plumb bob, which is a weight with a pointed tip and suspended from a string, is used to ensure verticality of the bars. Grooves are cut into the edges of the panel to facilitate bonding between adjacent walls. The wall panels are assembled as shown in Fig. 7.

After every third cavity is infilled in the structure, if the empty cavities are left as such, there is a chance of breakage of the panels, or cracks might develop in case of nailing or screwing. So the empty cavities are filled with quarry dust mixed with 5% cement and water. If electrical connections have to be given, the cavity is left empty and filled later.

For the construction of a sunshade, cavity on the top portion of the window is cut open and a reinforcement is inserted and concreted. Then the remaining height of cavities is infilled with concrete.

The floor panels are lifted horizontally and laid on the supporting wall panels, giving a bearing of 40 mm. Spreader bars, with soft slings are used for placing them to prevent any probable damage as shown in Fig. 8. Concrete tie beams connect panels to the walls at all junctions. Every third cavity in the GFRG panel is cut open and the concrete beams concealed by the reinforcement cage are placed inside. A steel welded mesh is placed on top of the slab and embedded in a screed of concrete. Plywood is provided throughout the perimeter of the floor. For fixing tiles in kitchens and bathrooms, special additives have to be used.



*7(a)* *7(b)* *7(c)*

*Fig. 7 Assembly of wall panels;*
*7(a): Lifting of wall panels using crane; 7(b): Erected wall panels;*
*7(c): Pouring of concrete into wall panel cavity*

Fig 8: GFRG panel used as a staircase

Fig 9: Panel lifted using spreader bars

Similarly, staircases are also made using GFRG panels as shown in Fig. 9. The flange is cut open and filled with reinforced concrete again. The upper storey, parapet walls and the staircase headroom is also done in the same manner.

Water proofing, suitable for GFRG and concrete, is done for the panels which prolongs their life. Horizontal joints between plinth beams and panels, floor slab and external wall panels, panels in wet areas like bathrooms and toilets are waterproofed according to standard treatments which have been defined in manuals.

The painting of the walls is non-conventional as the walls are water resistant. A primer is applied onto the panel first, before application of the paint. The primer helps in bonding the paint and enhances the abrasion resistance of the panel material. A thin layer of gypsum based wall plaster or cementitious wall putty, mixed with water proofing chemical is applied to give a smooth finish. The chemical is used to prevent peeling off from panel due to rains. The need of plastering is completely eliminated.

These buildings can be as high as 8-10 floors in a low seismic region. Due to the low self-weight of the building, the risk is much less compared to regular structures. The concrete infills are primarily responsible for the resistance in shear generated by lateral loads due to earthquakes. The panels were subjected to monotonic (tension and compression tests) and cyclic loading (repeated application of stress and strains) to study the strength in seismic regions. It was found that there were vertical shear cracks, but the concrete core was undamaged. Ductile behavior was exhibited which was important in earthquake prone regions. In case of multi-storey buildings, reinforcements are provided in orthogonal directions. This ensures safety of the construction during any earthquakes.

In relation to the research work done by the team, GFRG has been now approved as a building material in India for upto 10 storeys by the BMTPC (Building Materials Technology Promotion Council). Manuals on structural design, waterproofing as well as schedule of items and rate analysis have been published in this regard. A BIS code, on design and construction has been prepared and is likely to be released in the following year. These guidelines and standards are crucial for engineers to bring the story to reality. A demo building has been

*Fig 10: Demo building at IIT Madras*

*Fig 11: Mass housing in Nellore*

*Fig 12: Hostel construction at IIT Tirupati campus*

constructed inside the IIT Madras campus as shown in Fig. 10.

This building is a two-storeyed, four apartment residential building with a built-up area of 184 sq. m and a total cost of just Rs. 23 Lakhs. The foundation was laid in 11 days and the entire superstructure was finished in 29 days and the panels were actually transported to the campus. Currently, 40 housing units are being constructed in Nellore, sponsored by BMTPC as shown in Fig. 11 and four storeyed hostel buildings are in construction in IIT Tirupati campus as shown in Fig. 12.

Affordability, rapidity and sustainability are the key highlights of the building system. At least one-fifth of the production cost has been saved, and the lifetime of the building is same as that of a conventional building. But certain challenges remain to bring the idea into action for mass housing in practical terms. The manufacturing units for the panels have to be made available in all regions and ensure ease of availability. Builders must be ready to take up projects using this technology. Architects, structural designers, and workers must be trained in terms of the construction methods. Moreover, people must be made assured of high quality, durable and affordable solutions.

This great potential technology is definitely a ready example of research directly helping the hand of the society and brings in one of the basic needs of the people. New innovations in mass housing lead to the betterment of society and quality deliverables.

## Professor's Bio

Prof. Devdas Menon is currently a Professor in the Department of Civil Engineering at IIT Madras, engaged in teaching, research and consultancy in structural engineering (with a focus on the design of concrete structures). He has a special interest in improving the prevailing engineering practice in India, with regard to various codes of practice, design and construction practices and quality of technical education.

## Author's Bio

Vidya is a research scholar at the Department of Biotechnology, and works on Plant Cell Bioprocessing. She is always excited about getting to know the answer to the "Why" question for anything that captivates her. She is a passionate classical dancer and also loves to sing and play the keys. She often spends her free time reading novels and watching english series.

# Scratching the Surface: Light, Electricity, and the World of Thin Films

**Professor**

Dr. Parasuraman Swaminathan

**Writer**

Shivani Guptasarma

**Editor**

Ranjani Srinivasan

The ability to engineer materials at the nanometre scale has opened up a world of possibilities. The Electronic Materials and Thin Films Lab at the Department of Metallurgical and Materials Engineering explores, among other things, new ways to make and use nanostructures. This article describes how such research leads to the creation of better transparent materials: surfaces that reflect very little light, and see-through, foldable electrical devices that can be, quite literally, printed out of a printer.

"Your eyes are like the diamond bright, but mine are dull as lead."

-Mary Howitt, the Spider and the Fly

Shiny eyes can be an insect's downfall. As they fly through the night, moths need to avoid the attention of birds, bats, mice, and a host of other creatures. Nature has evolved a brilliant mechanism for this: features on the textured surface of their eyes, a million times smaller than a millimetre, reflect the light in such a way that it cancels out the light coming directly towards the eye. In effect, therefore, very little light makes it out of the maze of these structures – called nanopillars – and to the eye of a potential predator.

The idea of a surface that reflects very little light is one that humans have plenty of use for. Anyone who has had their spectacles flash like window panes in photographs, completely obscuring their eyes, would understand the trouble. Birdwatchers and the military have even stronger reasons to fear being given away by glinting lenses. Finally, there are devices such as solar cells, that can find greater acceptance as energy technology if they manage to use almost all the light that reaches them, without sending any away. Dr. Parasuraman Swaminathan, Associate Professor at the Department of Metallurgical and Material Engineering at IITM, explains how his team at the Electronic Materials and Thin Films Lab works on new ways to create such surfaces, and other devices that involve laying very thin layers of one material over another.

Light waves that are out of phase cancel each other out through what is known as destructive interference, and there are two ways to use this to make surfaces less reflective. The first is to use a thin coating of a different material, or of a series of several different materials. Every time light passes from one layer to the next, some of it is reflected away. The layers can be designed in such a way that the reflected light is exactly out of phase with the incoming light. There are several problems with this approach, however. The material used to form a thin film needs to be carefully selected for its refractive index, the factor by which it slows down and bends a ray of light entering it from empty space. For instance, to reduce reflection of light passing from air into glass, the squared refractive index of the material of the coating film needs to be nearly equal to the product of the refractive indices of glass and air. Magnesium fluoride is one of the few materials that works, but there is not much choice. One may also deposit multiple layers of different materials. The greater the number of layers, the less stable the coating, until the mismatch of properties at the mating surfaces causes layers to start peeling off and cracking, like the crust on a cake or a loaf of bread.

*Fig 1: Krishna uses this high vacuum coating unit to deposit thin films of copper on silica (oxidised silicon) by a process known as thermal evaporation. The source metal is heated in a molybdenum boat in high vacuum, by passing an electric current through it. The metal (copper, in this case) evaporates and condenses on the surface to be coated (here, silica).*

A far better method is to imitate the moths more directly, by creating surfaces textured at the nanometre scale. This can be done by etching out parts of the surface with chemicals, and trying to control how much material is removed and how it is distributed. This way, the change in refractive index as light goes deeper into the surface is far more gradual. Mr. Krishna Kumar, a research scholar at the lab, tells me how a part of his doctoral work involved doing this with nanoparticles, and how he made an exciting new kind of nanopillar almost by accident.

It began, like many happy accidents in research, with trying to solve a different problem. The electronics industry uses thin films of copper to create delicate circuitry on glass. These films shrink into patches when they are heated, a process called dewetting. One way to stop this from happening is to deposit a smattering of nanometre-sized particles of silver onto the film. The copper film is divided into regions called grains, and when it is heated, the silver nanoparticles move to corners where the boundaries of three grains meet. These particles hold the grains together, and keep the film from splitting up.

Having two metals on the surface of the glass (one as a film and one in the form of nanoparticles), therefore, makes it harder to dewet. On heating even further, however, dewetting does occur, and this time, the film shrinks into nanoparticles containing both materials, irregularly shaped at first, but nearly spherical at higher temperatures. Such "bimetallic" nanoparticles come in various shapes and sizes, and have been made by several techniques in the past, including dewetting a double layer of thin metallic films. Some of them have a core of one material surrounded by the other, while some have the two materials mixed uniformly as an alloy. In this case, the particles are segregated, that is, each has a copper side and a silver side, with a shared interface (these are named Janus structures, after the two-faced Greek god). Bimetallic nanoparticles are useful for the same reason that alloys are useful in traditional metallurgy; the properties of different materials can be brought together. In the area of thin films, for example, the electronic properties of one material can be married to the optical properties of another, in the same coating. Krishna mentions this only as an aside; his work is about using the nanoparticles to create textures on the silica surface, and then removing both copper and silver altogether.

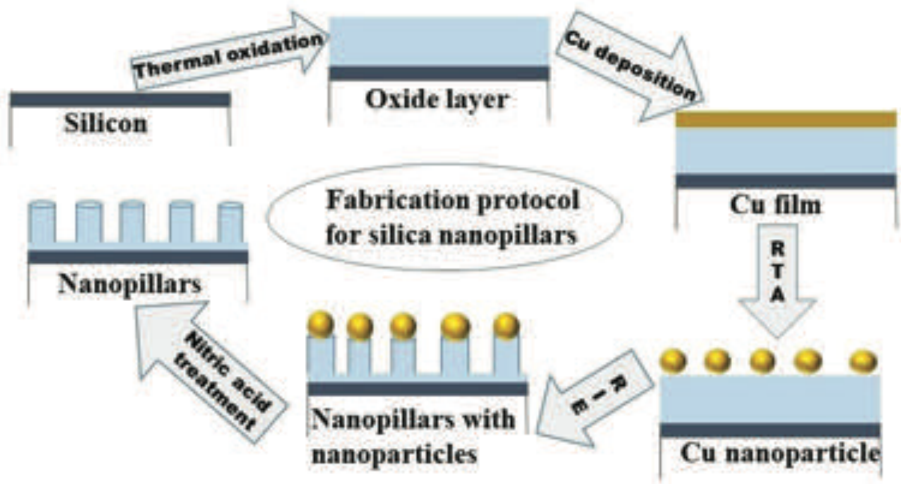



*Fig 2: This diagram shows how "single-diameter" nanopillars can be made using copper nanoparticles. Similar principles are used to make "dual-diameter" nanopillars, shown in Fig. 3, with bimetallic nanoparticles. "RTA" stands for Rapid Thermal Annealing, which causes dewetting, and "RIE" for Reactive Ion Etching, which creates nanopillars.*

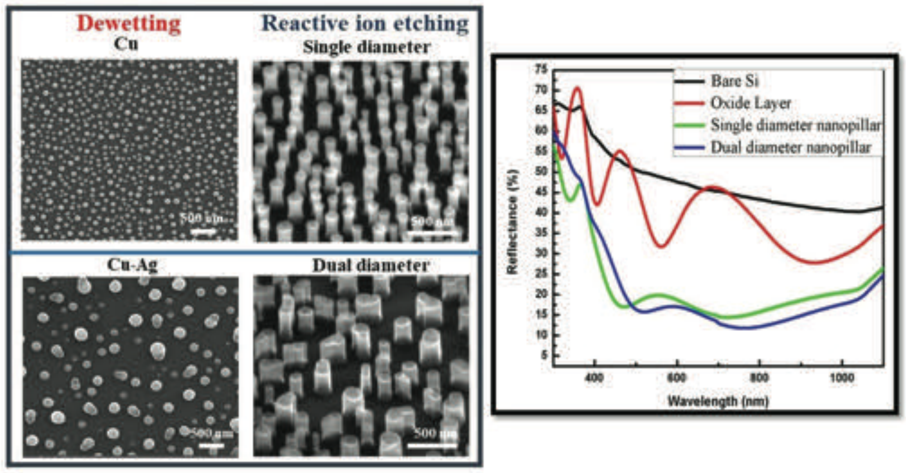



*Fig 3: On the left are photographs of the silica surface taken under a Scanning Electron Microscope (SEM): the results of the process shown in Fig.2, for copper nanoparticles above, and copper-silver nanoparticles below. The shape of the nanopillars is altered accordingly. The graph on the right shows that for a large part of the spectrum, the second kind of nanopillar reduces the amount of light reflected.*

Using a technique in microelectronics fabrication called Reactive Ion Etching, trifluoromethane is used to etch deep pits into the silica surface, while the bimetallic nanoparticles sit atop it. What is beautiful about this process is that this etching can be controlled by processes that came before it, because the nanoparticles protect the surface beneath themselves from being attacked by the etching chemical. This means that when the etching stage is over, a forest of pillars is formed, each capped by a nanoparticle. Since this particular experiment started with 'Janus' nanoparticles, each nanopillar is shaped like a pair of pillars stuck together. After nitric acid washes the metals off, a twin-bowl is left on top of each pillar. It turns out that this more complicated structure is better for destroying reflectance than regular nanopillars. The good news is that the size and density of nanopillars is in the hands of the designer, and can be played with to find the best conditions for low reflectance. The temperature at which dewetting happens, and the time for which it is allowed to go on, decides how many nanoparticles (and, consequently, nanopillars) are formed, and how closely they are packed. The time and conditions of etching decide the height of the pillars.

After finding out how best to cut down reflection from these surfaces, the next step is to experiment with them in the organic solar cells fabricated by Dr. Debdutta Ray and his team at the Department of Electrical Engineering. The two labs frequently collaborate, given that they are concerned with closely related areas of research. One result of this collaboration is the jointly supervised doctoral research of Mr. Nitheesh M. Nair, who is trying to refine a relatively new technique for making transparent conducting films. These would make good electrodes for solar cells and LEDs; they can also be used to make transparent antennas. A transparent antenna, Dr. Parasuraman points out, can be stuck anywhere onto a car's windows, without concern with interference from metal parts. Incidentally, Nitheesh is often to be found at my department, Engineering Design, where he works with Dr. Kavitha Arunachalam to test antennas that he has fabricated.

The processes used in Krishna's work – deposition, etching, and so on – are one way to fabricate devices and structures at micrometre and

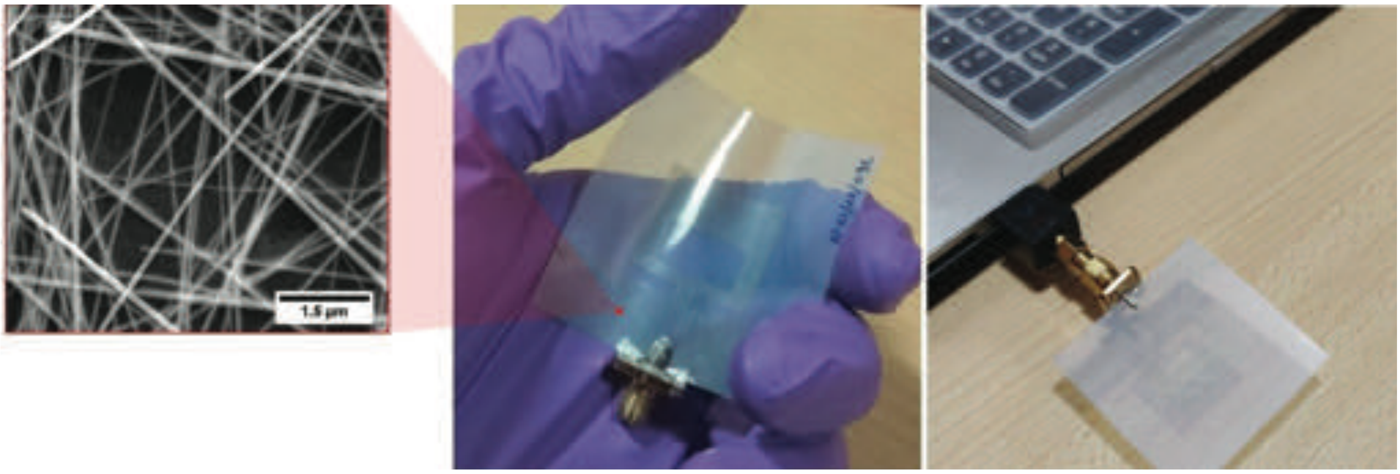



*Fig 4: The pictures on the left show a printed Wi-Fi antenna, and a SEM image of the nanowire-polymer film. On the right is the antenna in operation, connected to a laptop.*

*Fig 5: The custom-built printer receives instructions from a laptop connected to it, and writes a pattern directly onto a surface in conducting ink, using a syringe that can be moved horizontally and vertically across the "page". Commercially available silver nanoparticle-based ink is used here, because the ink developed by Nitheesh is transparent and would not be visible in a photograph. This fractal antenna was designed in collaboration with Dr. M. Sugavaneswaran, at the Vellore Institute of Technology.*

nanometre scales. A natural question, then, is whether it is possible to draw electronics onto glass and other materials, rather than resort to what is effectively a form of stencilling. A large part of the research at the lab is concerned with this aspect of thin film electronics: how does one print a layer of conductor or semiconductor, a few hundreds of atoms thick, directly onto a surface? How does one ensure that these work well as electrical and electronic components, while also displaying new properties like transparency and flexibility? These are some of the questions that Nitheesh works to answer. His work lies at the edge of modern research, yet evokes a picture of the scribes and chemists of centuries ago: he is trying to develop an ink that is thick enough so that it does not splash or overflow but runny enough to come out of a nozzle, and adherent enough to withstand wiping and bending. The difference is that this ink must conduct electricity.

Silver nanostructures appear again in this context; this time, in the form of nanowires. Nitheesh compares the suspension of these nanowires in a solvent to a spiderweb: it must be networked densely, so that it performs well electrically, but must be exceedingly fine so that light can pass through. Without a well-selected solvent, the nanowires would clump together, serving neither purpose. He settled upon a conducting plastic called PEDOT:PSS, after trying water and a number of organic fluids over a few months' time. PEDOT:PSS not only ensures that the nanowires are well-dispersed, but is itself able to conduct electricity, allowing for much thinner (and hence more transparent) layers of ink for the same functions. It also makes the ink harder to peel off. The products of printing are subjected to tests of their properties, for instance, by being bent and unbent thousands of times before checking the effect on their electrical behaviour. The ink is tested too, for surface tension, viscosity and conductivity.

Like any design process, this is a story of iteration and evaluation. The concentration of nanowires and the nature of the solvent, the parameters of the tests and the printing conditions, all come together to determine how easily one is able to fabricate an antenna or an electrode, and how well it functions under challenging conditions. There is no part of the procedure that is not the designer's responsibility. When some commercial printers at the lab failed because nanowires frequently clogged their nozzles, Dr. Parasuraman, and his students at the time, teamed up with mechanical engineering undergraduates at the Centre for Innovation to customise a 3-D printer for nanowires (the undergraduates went on to make industrial 3-D printers, and founded a company called Tvasta Manufacturing Solutions Pvt. Ltd.). This is the machine that Nitheesh and others use to print their electronics.

These researchers, and others around the world in this area, are participating in a reinvention of printing, of sorts. The technology must be developed piece by piece, and put to the strictest tests: paper, ink, and press all take on a new meaning. Someday, it should be possible to print an entire solar cell – electrodes as well as semiconductor junction. Medical implants would


*Fig 6: The Electronic Materials and Thin Films Lab, September 2018. Dr. Parasuraman fifth from right, Krishna fourth from right, Nitheesh second from right*

become accessible to everyone, and touch-sensitive screens would no longer shatter at the slightest provocation. New ways of making electronic devices, together with a better understanding of how light and electricity can be made to interact with materials, could give us the ability to engineer materials at a level that could only have been dreamt of a century ago.

**Professor's Bio**

Dr. Parasuraman Swaminathan is an Associate Professor in the Dept. of Metallurgical and Materials Engineering at IIT Madras. He graduated from IITM, with a B. Tech and M. Tech Dual degree. He then completed his PhD from the University of Illinois, postdoctoral fellowship from Johns Hopkins University, and worked at Intel Corp as a Yield Engineer, before joining IITM in 2013. He has an online course on NPTEL platform and has published a textbook (Wiley) on semiconductor materials. His research interests include printed electronics and thin film deposition. He was awarded the Young Faculty Recognition Award in 2018, by IITM, for excellence in teaching and research.

**Author's Bio**

Shivani is a final-year Dual Degree student at the Department of Engineering Design. She is interested in the geometry, mechanics, and design of both robotic manipulators and human limbs, and hopes that the former will someday be able to do all that the latter can. She enjoys books, music and new languages, whether of new places or of other disciplines.

# Corrosion - A Multi-scale Perspective

**Corrosion is a pervasive phenomenon which when taken for granted, leads to many a disaster. The research group of Dr. Ilaksh Adlakha from the Department of Applied Mechanics aims to perform systematic multi-scale studies to capture the essential ideas of corrosion and come up with a predictive model for this phenomenon. This article encapsulates the core principles behind such studies.**

**Professor**

Prof. Ilaksh Adlakha

**Writer**

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Every material reacts with its environment. If this interaction results in the destruction or deterioration of the material, it's called corrosion. Corrosion occurs everywhere, all the time. The most well-known example of corrosion is the rusting of iron. It happens in huge statues and also in our door hinges. Because of this ubiquity, the importance of understanding corrosion cannot be understated.

There have been many instances of catastrophic failures due to corrosion, including the collapse of buildings and bridges. If we ignore corrosion, we pay for it. There are many ways by which there's a recurring monetary cost due to corrosion. There's no easy way to estimate this exact amount because we must include both the costs needed for preventive measures like coatings and those for repairs of corroded parts. The estimate of the cost of corrosion is close to 5% of the country's gross domestic product! The cost of corrosion often exceeds the damages caused by floods, cyclones, and earthquakes all put together. The entire economy will drastically change if there's no corrosion. Though the cost of corrosion is inevitable, much can be done to reduce it! One good way to do this is by a proper selection of materials and sound design. Dr. Ilaksh Adlakha and his research group in the Department of Applied Mechanics at IIT Madras work on this problem.

When asked about why he chose to pursue this field, Dr. Adlakha says, "One of the motivations is to find out how to engineer the next generation of environmentally resistant structural alloys." In marine applications, there is constant exposure to the harsh environment of sea water. If we observe, in our kitchens at home, the salt is never stored in a stainless steel container while most of our other storage containers and utensils are made of shiny stainless steel. The reason for this is that the chloride ions present in common salt are capable of breaking through the protective layer in stainless steel to cause corrosion. At a large scale, underground pipelines, underwater appliances, and containers in contact with highly corrosive environments are severely prone to many kinds of corrosion. Hence, naval structures like aircraft carriers and the aircraft themselves require a robust selection of materials.

If we think about the many ways by which corrosion can happen, it's incredible that we have made any progress at all! But it's not all bleak if there is some way to judge whether a material can tolerate its environment. It is for this purpose that we need essential insights about the mechanisms of corrosion to provide useful inputs that help us to sieve through the possible materials and pick some for the required application.

There are multiple length scales associated with any material. When we look at an object with our naked eyes, we see its shape, dimensions, and the material it's made of. Materials are primarily of two types: crystalline and amorphous. Crystalline materials have a regular arrangement of atoms over long distances whereas amorphous materials don't. Most metals in everyday applications are crystalline. If we observe the same object a bit more closely, say with the help of an optical microscope, we will then find that most of the objects around us are not made of just one kind of arrangement of atoms. Instead, the atomic planes are oriented in different ways. Each material is therefore divided into many regions based on the orientation of the atomic planes. These regions are called grains, and the areas at the intersection of two or more of these grains are called the grain boundaries (Fig 1). If we go much deeper in our exploration, looking at the material magnified a billion times compared to the naked eye, we reach the scale of atoms. Depending on what property of the

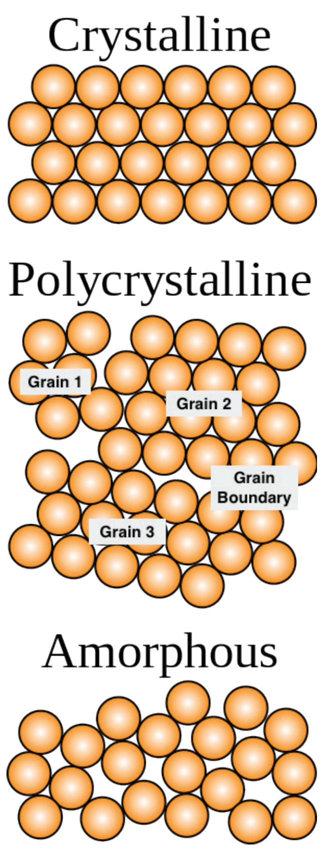



*Fig 1: Arrangement of atoms in different types of materials. A polycrystalline material is made of different "grains".*

material we study, different length scales come into play.

If we wish to study corrosion, it's not sufficient to stick to just one length scale. This multi-scale nature makes studying corrosion challenging, and it is a phenomenon that people have been looking at for over a hundred years but haven't yet understood fully. We know there is some amount of degradation of performance, but it remains to be fully understood how to break down the study of corrosion across different length scales.

Corrosion can be studied as a macro-scale phenomenon, where the material gets "eaten up" due to the chemical reactions. When examined at the microstructure level, the grains and grain boundaries play a role. The material can selectively deteriorate along the grain boundaries leading to the material zipping and opening up along the grain boundaries and causing failure. At the atomic scale, the hydrogen that can evolve as a part of the electrochemical reactions gets accumulated in specific regions, leaving behind areas that are susceptible to failure on the application of loads.

"As a part of my area of research, I have focussed on looking at the different scales in which this phenomenon happens", says Dr. Adlakha. "The hydrogen that accumulates starts degrading the mechanical performance, both by modifying how the material behaves under load and by changing the surface electrochemical reactions themselves after this application of load." Having worked on different scales, he is trying to link them into one consistent idea that can help predict, by some estimation, the contribution of each of these phenomena to mechanical degradation.

There are various techniques of study used at each scale. For instance, at the atomic level, we can imagine the atoms to be little balls or spheres. We can then use the same laws that Newton may or may not have come up with after the customary apple fell on him: Newton's laws of motion. These laws can be used to estimate how the atoms (spheres) move around just like how they can help in understanding the movement of macroscopic objects. We do this by solving for the velocities of the atoms from thousands of simultaneous equations (the exact number depends on the number of particles we want to model) using codes written for the purpose. Once the numbers are "crunched", we can simulate which regions the hydrogen atoms segregate to. Other techniques like phase-field modelling, crystal plasticity, and multiphysics simulations using tools like Comsol® are used to quantify plasticity (studying how the material permanently deforms under loads) and reaction kinetics during the electrochemical reaction. Once we have results from simulations at different scales, we need to look at the contribution of each of them to the big picture. This contribution changes from material to material.

It needs to be admitted that in our pursuits to isolate the study at each length scale, we have purposely ignored some aspects of the phenomena at other scales. But all of these are at play when corrosion happens in real life. This interplay of different phenomena is therefore only captured via experiments. Quantifiable parameters from experiments are crucial to thread together the scales by deciding on the weight to be given to each scale. "The overall idea is that, when you do a hierarchical study across many length scales, we can't carry all information from each length scale. We need to carefully choose which ones to", explains Dr. Adlakha. "We can feed everything into a predictive framework and see from experiments how far the results match. Along with my PhD students, I am trying to capture information from different scales and develop such a predictive model alongside experiments."

So, in the end, these studies aim to come up with a robust model across length scales, hierarchically, to ensure that we are in a position to predict when the failure occurs. Such a model will not only save money but also indirectly save time and needless to say life! This model can help understand corrosion better, thereby making it possible to either design new materials or pick existing ones with tailored properties to fit with the environment for different applications. The "MultiScale Mechanics" research group headed by Dr. Ilaksh Adlakha is driven to take us there.

## Professor's Bio

Dr. Ilaksh Adlakha is an Assistant Professor in the Department of Applied Mechanics, IIT Madras. He obtained his PhD from Arizona State University in 2015. His research interests lie at the interface of solid mechanics and materials science with a special focus on the development of structure-property relationships across multiple length scales.

## Author's Bio

Mythreyi is a fourth-year undergraduate student and is stoked about pursuing an interdisciplinary dual degree in Computational Engineering, which directly feeds her interests in Computational Materials Science. When not tinkering with digital tools that she stumbled upon by proactive serendipity, she can be found reading books and writing. She has elaborately created a blog in her head; she hopes it will "materialise" one day.

# On A visit to SERG facility

**SERG stands for Solar Energy Research Group. It is a team comprising of BTech, MTech, PhD students and Postdoc led by Prof. Aravind Kumar Chandiran of the Chemical Engineering Dept. at IIT Madras. This article provides an insight into a brief overview of the research that is underway in their lab.**


**Professor**

Prof. Aravind Kumar Chandiran

**Writer**

Ivana Ashmita Minz &
B Sumanth Kumar


### The Journey Thus Far

The history of mankind can be characterised by the wonderful journey from a primitive lifestyle to a technologically advanced one through a series of discoveries, inventions and innovations. It all started with the invention of the wheel which rolled us from the stone age to the modern age where we have now reached the milestone of being able to develop capabilities to understand artificial intelligence. How far will this journey continue? Is the world at its saturation point of all the technological breakthroughs that can be realized?

For instance, mass in its totality, can

neither be created nor destroyed. Even so with energy, with the added flexibility of being able to convert one form of energy to another. Revolutions upon revolutions in the energy sector have added an exponentially growing impulse to the stationery world. In the starting days of the discovery of what we one might refer to as conventional sources of energy, we enjoyed the fruits of that discovery without realizing the fact that these resources wouldn't be recovered again but that they would go on to decay with time.

At some time in course of our journey we may reach a point where all such non-renewable energy resources that have brought us so far would no longer be reliable and become scarcely available. Does that mean we will end up from where we started? Engineers and scientists have grappled with these questions for a long time. And they are optimistic. The way ahead, they suggest is to tap into an imperishable energy resource - the Sun.

Tapping into the potential of the sun is an ancient science. Ancient Egyptians used solar energy to heat their homes. Early scientists such as Alhazen, refined the understanding of how mirrors and lenses could focus sunlight and generate heat. French engineer Salomon de Caus was one of the first to utilize solar energy to do useful work, by using a burning glass to power a small water pump and fountain in 1615. Today, we're looking at the possibility of generating the highest form of energy we know i.e. electricity from the Sun, not just on a lab scale, but to make it a viable technology for commercial use as it would be required to empower billions of households across the world.

## A Road Marked by Challenges

Electricity is that form of energy which we obtain on account of movement of electrons from one location to another. Therefore, to generate electricity from solar energy, we must ask as to how we can trap solar energy and channel it to transport electrons across a conducting material. The conversion of solar energy into electricity is achieved using a device called the 'photovoltaic cell'.

Semiconductors are materials having conductivity levels between conductors and insulators (for example- silicon, germanium, gallium-arsenide). In general, the conductivity of a material depends upon the energy gap between the conduction and valence bands. Usually for intrinsic (pure form) semiconductors, the energy gap is high (eg: Si-1.1eV, Ge-0.72eV). In order to increase conductivity, the energy gap is reduced via the addition of foreign elements to the base element. This process is called doping. Based on the kind of doping agent used, we can obtain n-type and p-type semiconductor. If group-V elements added as doping elements it results in an n-type semiconductor wherein 5 valence electrons form 4 covalent bonds with silicon atoms, leaving one electron as unbonded which introduces an extra donor band near to the conduction band and thus, decreases the energy gap (eg: Si-0.05eV, Ge-0.01eV). If group-III elements added as doping elements, it results in a p-type semiconductor wherein 3 valence electrons form 4 covalent bonds with silicon atoms, in which one bond is short of one electron leading to the creation of a hole. This introduces an extra acceptor band near to valence band thus decreasing the energy gap.

Traditional solar cells consist of p-type semiconductor below n-type semiconductor in contact, with metallic layers on the top and bottom. The top layer is a metallic grid in which anti-reflective layer is incorporated. When placed under the sun, photons from the incident light excite an electron in the p-type semiconductor from its lower energy valence band to higher energy conduction band. Following which, separation of charge carrier happens by injection of electrons into n-type and holes are transported within p-type to reach external contact. This phenomenon is called the photoelectric effect.. When this cell is connected to external circuit, the electrons flow through the circuit back to p-type element where they recombine with holes. In this way solar energy is converted into electrical energy.

The problem with silicon solar cells is that it requires thick layered doped silicon to absorb the sufficient amount of solar energy and secondly, high cost of manufacturing due to need of large amount of expensive processing methods to generate ultrapure silicon. To overcome these problems, amorphous or thin film technologies using inorganic materials like Cadmium-Tellurium (CdTe) have been developed, but efficiencies of these solar cells are less than the crystalline silicon solar cells (25%). The challenges in this area lie predominantly in finding economically viable and environmentally friendly materials that can offer high efficiencies. This requires pushing the boundaries of materials science and delving deeper to understand how charge transport occurs across different materials.

At IIT Madras, Professor Aravind Kumar Chandiran in the Department of Chemical Engineering, and his team (SERG - Solar Energy Research Group) are investigating photoelectrochemical solar energy conversion devices. Their research include developing new semiconductors and tuning existing semiconducting materials for enhanced solar-to-electricity/ fuel conversion efficiency. This is of utmost importance since the absorber material is the main component of a solar cell/solar fuel systems, as it plays the role of absorbing sunlight and transporting the resulting charge

**Cost, efficiency, and reliability of PV modules for established solar cell technologies, important for scaling toward 1-TW installation levels; italics indicate yet to be proven projections. Additional criteria, such as elemental abundance, capital expenditures, environmental concerns, become important for scaling to the 10-W level, and new PV absorbers should have the potential to meet all these criteria.**

| Photovoltaic technology | Module cost | Module efficiency | Module reliability | Capital expenditures | Environmental concerns | Elemental abundance |
|---|---|---|---|---|---|---|
| Si | Low | High | Good | High | No | High |
| CdTe | Low | High | *Good* | Medium | Yes | Low |
| CIGS | Medium | *High* | *Good* | Medium | No | Low |
| III-V | High | Very high | *Good* | Medium | No | Low |
| MAPI | *Low* | *High* | *Bad* | *Low* | Yes | Medium |
| New absorber | *Low* | *High* | *Good* | *Low* | No | High |

*Fig 1: A comparison of materials for PV technology*

carriers to electrical contacts. At present, there is no material as such that offers the benefit of efficiency, cost, and reliability all at once. The team is also engaged in trying to understand the fundamental electron transfer dynamics at the interface of semiconductor-electrolyte in order to improve the photovoltaic conversion efficiency.

The Dye Sensitized Solar Cell (DSSC) or the Graetzel Cell is one kind of a photoelectrochemical solar cell device that can be used to convert solar energy to electrical energy. It can deliver an efficiency of about 13% . Its ease of fabrication and use of simple materials and equipments makes their cost of manufacturing lesser than silicon based solar cells. DSSC consists of a transparent electrode covered by a dye coated mesoporous titanium dioxide layer. The second electrode is separated by an electrolyte which is usually iodide/ triiodide. Whenever the dye absorbs solar energy it excites electron from its highest occupied molecular orbitals (HOMO) to low occupied molecular orbitals (LUMO). The dyes are designed in such a way to have very good electronic overlap with the conduction band of titanium dioxide. This facilitates the injection of photogenerated electrons in the LUMO level of the dye to the conduction band of titanium dioxide and transported further to the transparent conducting electrode. The holes located in the HOMO level of the dye is injected to the redox mediator, which is further regenerated by the transfer of electrons via the external circuit through the second electrode. Advantages of this solar cell over crystalline silicon solar cells is that it is much cheaper to fabricate and cost/kWh is projected to be lower than the existing commercial panels. These devices can also be used effectively for under low light conductions. For e.g. in the case of rooftop solar collectors, they are able to work under cloudy skies and non-direct sunlight. However, the major disadvantage of use of liquid electrolyte is that it is highly dependent on temperature stability since it freezes and expands at low and high temperatures. Also, these solvents need to be sealed carefully as they are hazardous to humans and the environment. In order to overcome these disadvantages, solid state dye sensitized solar cells are now being developed. Here, the liquid electrolyte is replaced with solid conducting materials.

Although solid state dye sensitized solar cells tend to degrade faster and have less flexibility, they have nevertheless gained the interest of researchers as they promise high efficiencies with the combined use of perovskites. A perovskite is any material with the same type of crystal structure as calcium titanium oxide ($CaTiO_3$). The perovskite of interest for solar cells is a hybrid organic-inorganic lead or tin halide-based material, as the light-harvesting active layer. The most commonly studied perovskite absorber is methylammonium lead trihalide ($CH_3NH_3PbX_3$, where X is a halogen ion such as iodide, bromide or chloride). These materials can deliver exceptional power conversion efficiencies already exceeding 22% at the lab scale. This material promises high efficiency, reduced processing costs, flexibility, and semi-transparency. Several disadvantages cloud the commercialization of perovskites right away. This can be mainly attributed to the toxic effects of lead and instability of the perovskite material, which leads to a shorter lifespan of the device. Prof.Aravind's team is seeking to understand the recombination dynamics of photogenerated charge carriers in these devices and to improve the device efficiency by modifying the semiconductor-perovskite interface. Also, in order to address the drawbacks of a perovskite solar cell, they are looking for new hybrid perovskite materials free of heavy elements including lead (Pb), and improving the device stability for long term performance.

**Harnessing solar energy is only one part of the problem. What about storage?**

Energy storage in the context of solar cells is of high importance with regard to reducing load on transmission and distribution wherever solar cell networks are installed. At present, power is generated in the plants and coupled to the grid and from there it is distributed to the customers. In times of emergencies, such as blackouts, these storage systems can be used as backups and also to meet the high demands during peak hours. But since the conversion efficiencies remain low, meeting this demand readily would require a more reliable source of energy. This is where solar energy stored in the form of chemical fuels can help. Prof. Aravind's team is currently exploring two ways to achieve this end, namely - solar water splitting and CO2 reduction.

Solar cell water splitting is an artificially run photosynthesis process (APS) designed to store solar energy in the form of chemical fuels through hydrogen evolution. Solar energy is stored in the form of chemical bonds, by formation of hydrogen and oxygen molecules from water. The vast stored energy can be released via the reaction of hydrogen and oxygen to produce water molecules.

Two pathways have been identified to achieve this end. The first is a single absorber system wherein there is a single light-excitation site for the electron while the other is a two-step process with the excitation of the electron to the required energy level happening at two different absorbers instead of just one as in the first case. The latter is also referred as tandem devices. The overall process requires an activation energy of more than 1.83 eV. The tandem devices provides the advantage of utilizing lower energy sunlight i.e. infrared wavelengths, making room for the use of several combinations of materials. Prof.Aravind's team seeks to address this issue by developing new visible/near-IR absorbers, selective catalysts and more. The efficiency of the water-splitting device depends heavily on the choice of material and its structure. Also, since this process is more complex and fairly difficult to control, they are researching ways to improve the stability of the device and ultimately improve the energy conversion efficiency.

This water splitting technology can be integrated with other renewable energy systems such as wind or solar in coastal areas where a facility for the same can be put up. Sea-water can be harnessed and sent to the APS systems for hydrogen fuel production which can be transported or stored as per requirement. Such a system

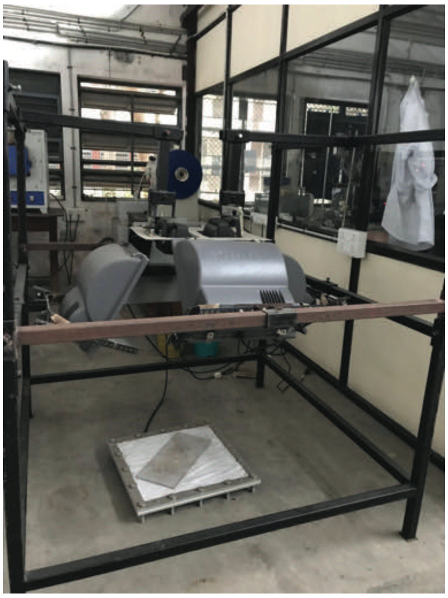


Fig 2: The solar simulator designed by students


Fig 3: A furnace assembled by students

can be the future power-house for many coastal neighbourhoods.

## Innovating Along The Way

The bulk of Prof. Aravind and his team's research work centers around projects funded by prestigious institutions such as Department of Science and Technology (DST), Board for Research and Nuclear Sciences) BRNS, ISRO, CSIR, Department of Biotechnology (DBT) and IIT Madras. Every project is an opportunity offering a lot of scope for creativity. Some notable projects include - the development of solar rechargeable batteries, wherein efforts are directed towards trying to combine both harvesting and storage of solar energy in a single unit, developing large area solar panels for low orbit satellite applications, understanding fundamental issues that are present in the thin film solar cells and discovering methods to improve their performance.

SERG consists of students at different stages in the academic world, yet all share the this one thing in common: the zeal to unlock the answers to the intriguing questions concerning the development of solar cells that will go on to revolutionize the world in the days to come.

When we visited his lab, we also had the privilege to witness the innovative efforts of the lab group members towards designing and assembling their own equipments and customizing them as per their needs. For instance, a large area solar simulator for testing large solar cells costs around about 50 lakhs with a lifespan of merely 2000 hours. In order to cut costs, instead of using an actual lamp, they alternatively used 4 general lamps whose collective emission spectrum matched the solar emission spectrum. Similarly, for solar panel printing, they constructed a device inspired from devices used to imprint designs on t-shirts. Likewise, there was much innovation to be found in the lab, a lot of smart work than just hard work.

Their lab possesses state-of-the-art instruments including (i) steady state and time-resolved photoluminescence


*Fig 4: A sneak peek into the various instruments in the SERG Laboratory.jpg*

spectrofluorimeter, with 100 ps resolution, (ii) UV-VIS-NIR spectrophotometer, (iii) home made solar simulator, (iv) home-made photoelectrochemical work stations, and (v) tunable light source.

In conclusion of our tour of the SERG facility, we learned from Prof.Aravind that research is not something that we start today and results will turn up tomorrow...it may take days and even years...we must be patient yet actively at work. We sure did sense this statement come alive in his lab.

## Professor's Bio

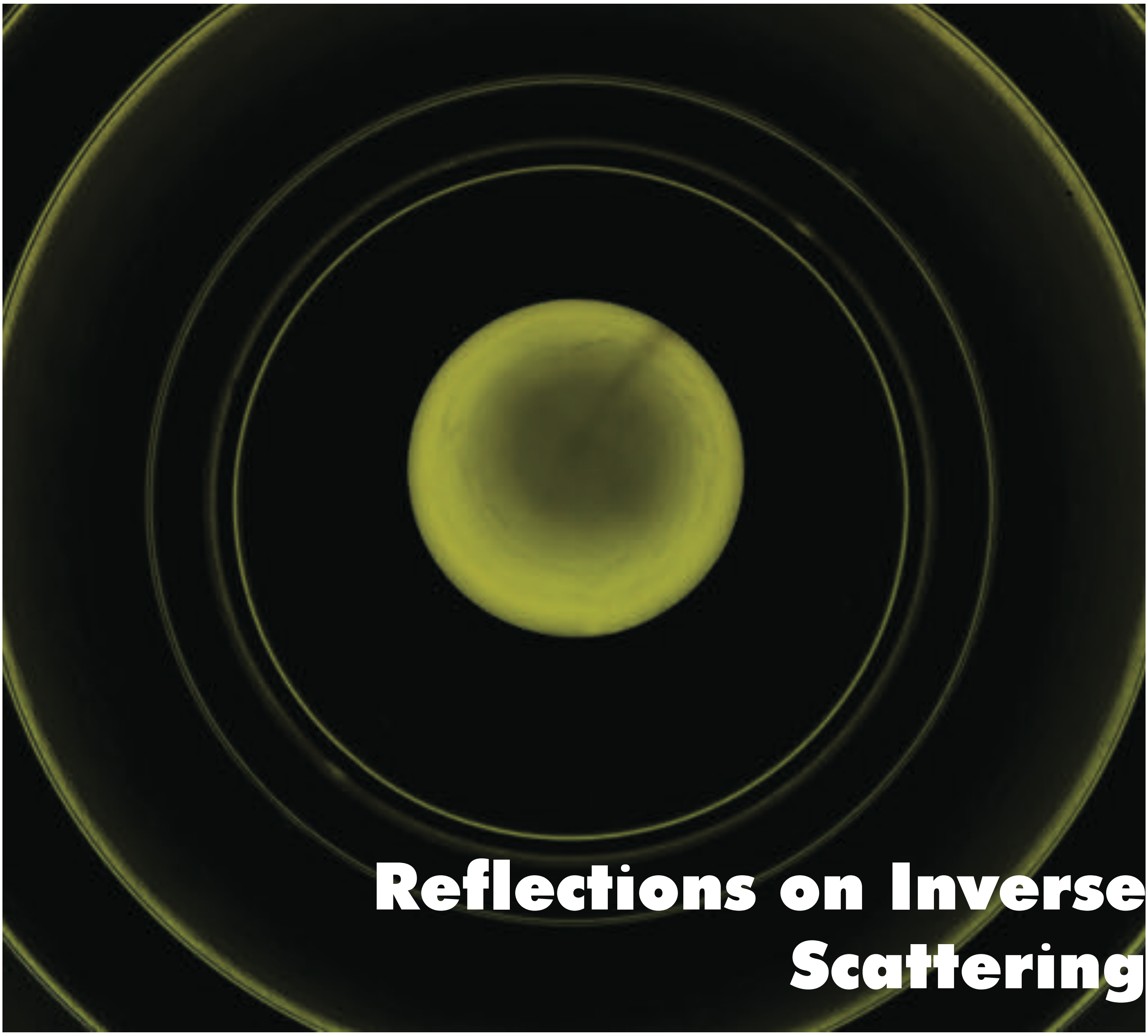
Prof. Aravind Kumar Chandiran is currently an Asst. Professor in the Solar Fuels Division - Indian Solar Energy Harnessing Center, IIT-M and an Asst. Professor, Department of Chemical Engg., IIT-M. He also serves as Adjunct Faculty at the National Center for Catalysis Research (NCCR), IIT-M. He may be reached at: aravindkumar@iitm.ac.in

For further information about SERG, go to the following link: http://aravindiitm.wixsite.com/solarenergy

## Author's Bio

Ivana is a final year undergraduate student in the Dept. of Chemical Engineering. She believes that humans have the highest responsibility of stewarding the world and its resources in a responsible and informed way and that education in itself is an excellent channel of making that possible.

Sumanth is a first year M.Tech student in Department of Applied Mechanics. his main interest is mathematics and has a zeal to learn new things.



# Reflections on Inverse Scattering


**Professor**

Prof. Uday Khankhoje

**Writer**

Adhvaith Ramkumar

**Editor**

R. Mythreyi


**Open problems are always exciting, primarily because they are open. While inverse scattering is a problem that has many vagaries and even more "solutions", it is also kind enough to provide elegant solutions to a whole host of engineering problems. A small peek into its world is what follows in the article, as we cover the work of Dr. Uday Khankhoje from the Department of Electrical Engineering, IIT Madras.**

Electromagnetic waves are literally everywhere, ranging from waves produced by distant neutron stars to the signals produced by our cellphones. This omnipresence makes them rather useful, and they are indeed used in a wide range of situations. Off the top of one's head, phones, radios, radars, microwave ovens and televisions come to mind as devices that make the most 'obvious' use of these waves. But there is an entire frontier of research that explores the applications of these waves to other less obvious situations such as remote sensing or non-destructive evaluation.

The research topic is the concept of Inverse Scattering, or in more layman terms: sensing an object without physically touching it. The problem is set up as follows: Given an environment with various objects, transmit electromagnetic signals into the environment and see (more accurately: process) how they scatter. The scattered signals contain information about the electrical and geometric properties of the system and environment. The grand question is, what can you say about the system? Naturally, there is quite a lot to be said about the system; it is a research problem after all! However, what has to be said is couched in rather tricky equations which are not very amenable to yielding information at our convenience. For example, can I detect a buried landmine by just processing the way it bounces off electromagnetic waves? Thankfully Electrical Engineers everywhere are working on this problem, and in our very own institute, it is a research interest of Dr. Uday Khankhoje in the Department of Electrical Engineering.

So far, we've been referring to the system as being modeled (i.e very well described) by a set of equations. What equations are these? It is the set that is the most extensively used for virtually all systems -- the fundamental equations of electromagnetics: Maxwell's equations. To this add a generous dose of signal processing and machine learning techniques and the ubiquitous engineering assumptions that are always made, and we have a viable model.

When we ask Dr. Khankhoje about the problem, he tells us that the primary issue is that the problem is not linear. What this means, effectively, is that changing the input signal does not lead to a proportional change in the way the system output behaves. Additionally, such a system is very intolerant to 'noise', a generic term for all the nonidealities and perturbations a real-world environment provides, which translates to changes in the scattered signal received. The general problem of inverse scattering posed above, is hence extremely difficult to solve, so much so that it is still an open engineering problem.

There are ways to circumvent this (rather daunting) inconvenience. But prior to that, we must investigate why this is important at all. Apart, of course, from the sheer pleasure of problem-solving, there must be a reason why this is studied. Since this is an engineering problem, the answer is a resounding yes, and the potential applications are extensive.

An application of inverse scattering is its use in biomedical problems such as the detection of breast cancer. In a recent medical survey [1], it was found that breast cancer is now the most common cause of cancer among Indian women. Moreover, the mortality rate is eight times higher in rural parts of the country as compared to the urban cities. While current methods such as X-ray mammography and MRI do offer solutions, their repetitive use is either dangerous, courtesy radiation, or too expensive. There is also an overall problem of lack of accessibility to diagnostic devices, as evidenced by the alarmingly high numbers in rural places. Microwave frequency based inverse scattering presents a potentially viable alternative because of its low cost and noninvasive nature.

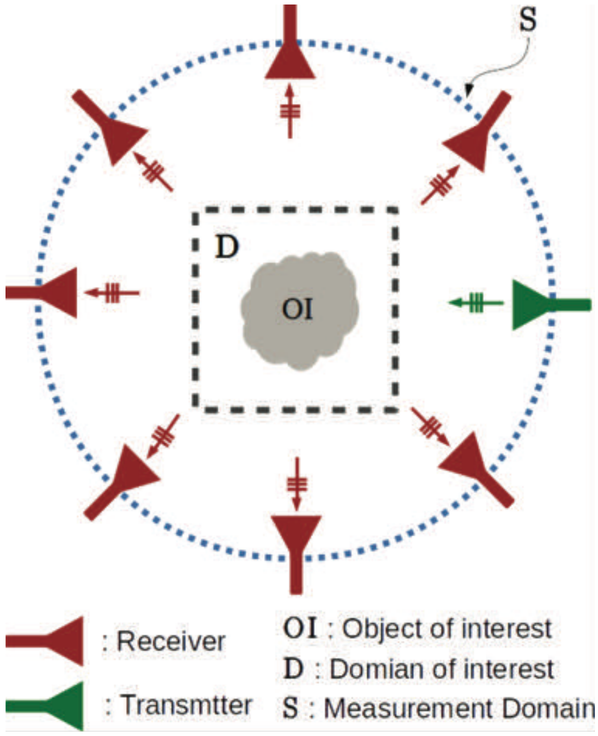



*Fig 1: Top view of a typical inverse scattering setup for breast cancer detection. The object is surrounded by transmitters and receivers, and the scattered field is collected for further processing.*

The scientific principle underlying inverse scattering is based on scattering -- the same physics which explains why a beam of light is split into a rainbow by a raindrop. Electrical Engineers work with a quantity called electrical permittivity, which is used to quantify how much a material responds to electric fields. Materials with high permittivity scatter waves in different ways than those with a lower permittivity. This is useful here because cancerous tissue has a very different electrical permittivity (usually higher) from non-cancerous tissue. With a cross-section of breast tissue and a set of receivers and transmitters, one can create a spatial map of permittivity on various locations of the tissue (see figure for a typical setup). Given access to a table (produced by the hard work of biologists) referencing the values of permittivity for various types of tissue, both healthy and cancerous, one can get a precise location for cancerous tissue.

There are issues with this treatment, however. One of the many features of the inverse scattering problem is that solutions are not unique, far from it. It is quite possible to obtain two different values of permittivity for the same set of signals. In such a situation, the value of the output is key, and thus merits intense scrutiny given the many solutions. We are lucky, in that other factors limit the scope of possible solutions -- for example, some physical constraints can be imposed on the obtained solution. This more or less offers some certainty to the results.

So, how is the problem solved? There are various techniques of solving, each applicable in certain situations, and each with its unique limitations. Of course, the first thing any engineer tries is to linearize the problem. Linear systems have been very well studied in the Engineering literature and come with a nice set of computational solution techniques and guarantees. These techniques work for a simple class of problems which feature low values of permittivity. But, as the universe would have it, real-life problems come with much larger values of permittivity, and linearization is a bad idea for trying to solve them!

An alternative is to use a nonlinear approach. This makes the math considerably harder and the computations even harder because of the large number of variables. What can help make life easier, is using some prior information about the signal we are trying to decode. For example, say that we are trying to recover a 200x200 pixel cross-section of breast tissue from scattered field data. This has 40,000 variables. Instead, if we look at the same image in some other domain, like a Wavelet domain, the number of variables drastically drops, as the signal is "sparse" in that domain. Using such signal processing tricks, among others, can help make the problem more tractable.

A very popular technique used for both linear and nonlinear approaches is gradient descent and its more advanced cousins. This technique first calculates the error for each estimate and attempts to minimize the error by finding the direction (in the space of variables) in which it decreases. The problem with this being, it's only too easy to encounter a local minimum, where the error increases in every direction, but the value of the error is not as low as it can be! To quote Dr. Khankhoje, "There are often local minima everywhere, and it's only too easy to fall and get stuck in them!" This issue is again solved by introducing other constraints.

Yet another approach which Dr Khankhoje and his students Yash Sanghvi and Yaswanth Kalepu have tried out recently, is to use ideas from Deep Learning to solve some of the harder knots within this problem. As mentioned earlier, this problem does not have a unique solution, but are some solutions more likely than others? The answer is a yes: a deep neural network, trained on a standard database of "digit" like images, offers clues as to which solutions are more likely than others. Plugging these clues back into the overall solution strategy has greatly expanded the range of problems that can be solved.

Such advances are taking him and his group closer towards realizing a proof of concept hardware setup that can actually serve as a low-cost tool for breast cancer screening. "There are enormous possibilities for healthcare, particularly in the rural sector", says Dr Khankhoje.

Apart from breast cancer detection, there are various other application areas for inverse scattering. As another example, inverse scattering is used when a satellite is used to measure soil properties or to get the topography of a region. The satellite transmits a signal, which is then scattered by the earth's surface. This scattered signal travels in various directions. The part of the signal that reaches the satellite is analyzed, hence offering a treasure trove of information, ranging from the height above sea level of the earth at that point to soil moisture.

In summary, an exciting open problem promises to open up a host of applications. Inverse scattering will soon open up vistas in everything from biomedical sciences to mapping locations and buildings. The techniques used to solve this problem themselves offer up a wide variety of applications in other fields, and all this is done from a relatively simple set of laws. As Dr. Khankhoje says, "For most situations every equation used is either one of Maxwell's equations or one derived from statistics" and it is certainly true that one can get a very long way.

## Professor's Bio

Dr. Uday Khankhoje is an Assistant Professor in the Department of Electrical Engineering. Inverse scattering is currently one of his research interests, among other problems in computational electromagnetics. Dr. Khankhoje received his undergraduate degree from IIT Bombay (B. Tech, EE) in 2005 and his Ph.D. from Caltech in 2010. He was a Postdoctoral scholar at the Jet Propulsion Laboratory (Caltech/NASA) from 2011-12, and a Postdoctoral scholar at the University of Southern California from 2012-13. His group website is at http://www.ee.iitm.ac.in/uday/

## Author's Bio

Adhvaith Ramkumar is a third year undergraduate student in the Department of Aerospace Engineering. He entertains a curiosity for science related material, and enjoys reading anything he can get his hands on.

# The "Flow" must go on: Decoding fluid flow in porous medium

How does the fluid flow in a porous medium? What are the direct applications of this research area in engineering and natural sciences? Though fluid flow seems to be ubiquitous in our daily lives, do we really know its versatile applications in a wide area of science and technology?

Prof. G. Suresh Kumar welcomes us with this intriguing question about this field. He, along with his active and dedicated group of research scholars from the Department of Ocean engineering at IIT Madras are engaged in probing the fluid behavior in a porous medium at the macroscopic scale which has huge implications in groundwater hydrology, geothermal reservoirs, petroleum reservoirs, subsurface disposal of nuclear wastes, etc. The research group focuses completely on numerical aspects of "single/ multi-phase fluid flow through a fractured porous medium" using different computational techniques.

**What is a porous medium?**

It is essentially a combination of both fluids and solids. It actually

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consists of solid-grains (solid-phase) and pores (aqueous phase). Fluids, in general, are characterized by an enhanced molecular mobility, where translation, vibration and rotation are allowed in the absence of tensile strength. Solids, on the other hand, are characterized by a restricted molecular mobility, where only vibration and rotation about a fixed mean position is possible with a definite tensile strength. In addition, the force of friction between fluid layers is independent of the applied pressure, whereas, it depends on pressure which compresses the two surfaces of the solids.

**Darcy's Law in action:**

Darcy's law is the momentum conservation equation that describes the fluid flow through a porous medium described at a macroscopic scale. The law was formulated by Henry Darcy based on the results of experiments on the water flow through beds of sand, forming the basis of hydrogeology, an area of geological science which deals with the distribution and movement of groundwater in the soil and rocks. Darcy assumed the fluid flow to be under steady state conditions in the absence of gravitational and capillary effects and the flow pertains to single-phase fluid flow (water). He also assumed the intrinsic permeability of the aquifer* to be strictly a function of the aquifer (or media property) and it does not depend on fluid properties. However, the description on the dynamics of multi-phase fluid flow through a porous medium fundamentally violates the assumptions of Darcy's law in the sense that the concept of effective or relative permeability is introduced and subsequently, the permeability becomes a function of fluid property as well in addition to the rock/media property. In a more technical language, introduction of multi-phase fluid flow is associated with a new physical parameter called capillary pressure**, which is absent in Darcy's law. Now this parameter stems from the detailed interaction at the pore-scale (microscopic scale), while Darcy's law is supposed to be dealt with the macroscopic scale. Also, it is not particularly feasible to measure this pore-scale capillary pressure at larger field scale. Currently, laboratory based capillary pressure is used to indirectly calculate the field-scale capillary pressure. So, there is a huge gap in translating the multi-phase fluid dynamics at the pore-scale to a larger field-scale application.

**Deviation from Darcy's law:**

The problem of fluid flow in porous medium gains new complexity when it is applied to describe fluid flow through heterogeneous reservoirs such as fractured carbonate reservoirs. Why?

Well, technically Darcy's law says that the volumetric instantaneous flow rate through a porous medium (also called Darcy flux) should be proportional to the pressure drop over a given distance in a homogeneously permeable medium ; and the volumetric flow rate should vary linearly with the fluid velocity. However, in a heterogeneous porous medium, both of these dependences become non-linear. This brings the limitations to the Darcy's law.

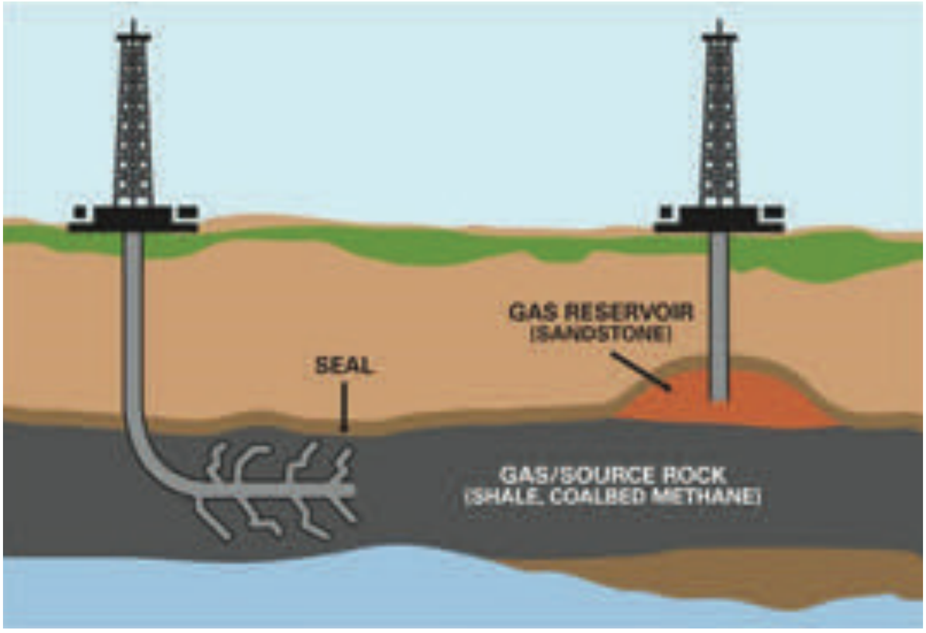


*Fig 1: Schematic for natural gas reservoirs[1]*

### Applications in Petroleum engineering: Inability of Darcy's law to correctly characterize heterogeneous reservoirs

So, what do we mean by a petroleum reservoir? A reservoir is defined as "the portion of a geological trap which contains oil and/or gas as a single hydraulically connected system" (Craft, 1991). Due to their petrophysical characteristics, oil and gas accumulation occurs mainly in sedimentary rocks as limestone, dolomite, and sandstone, where fluids are stored and distributed according to their densities. The main task of reservoir engineering is the optimization of the oil and gas extraction process (Essley, 1965). To do this, it is necessary to analyze/ interpret information generated from useful subsurface measurements, whose objective is the study and characterization of the behaviour of the reservoir. This is accomplished by models, which generate reliable and useful information to evaluate and determine the best exploitation strategy.

In the context of petroleum engineering, the diffusivity equation deduced from Darcy's law becomes pivotal for analyzing the reservoir characteristics. However, this diffusivity equation emerges from some mathematical approximations which limits its validity only to homogeneous and isotropic reservoirs. In reality, the case is always the other way round. We can hardly find such homogeneous and isotropic reservoirs and that too in the context of deep seated petroleum extraction. Further, following diffusivity equation by assuming the fluid (oil) to be incompressible may need further investigation. It should be noted that although oil can be compressed very slightly even at higher pressures, the elevated reservoir temperature will not allow the oil to be treated as a simple mechanical variable. It needs to be treated as a thermodynamic variable, where mechanical and thermal processes must be considered simultaneously. Thus, the concept of reservoir heterogeneity and the fluid compressibility associated with a petroleum/gas reservoir makes the conventional linear diffusivity equation based on Darcy's law to have a very limited application, while the role of non-linear hyperbolic (square of pressure gradient term) along with the consideration of fluid compressibility as a function of reservoir pressure takes the lead to better characterize the gas reservoir.

## Applications in groundwater transport: The limitations of Darcy's law

Another important and crucial aspect in describing fluid flow through porous medium arises when we intend to study the groundwater transport. Basically, water present in the subsurface environment of earth is called groundwater. Due to the increase of population over time, there is an increasing stress on groundwater resources to meet the ever increasing demand for freshwater, especially in arid and semiarid regions where drought conditions may prevail. Also, the protection of the quality of groundwater resources is important considering the variety of pollution sources. In order to do effective management and protection of groundwater resources, we need to understand the basic groundwater flow concepts and the fundamental transport processes associated with the contaminant movements. Hydrogeology (hydro-water, geology-the study of the Earth) is the area of geology that deals with the distribution and movement of groundwater in the soil and rocks of the Earth's crust. Contaminant hydrogeology is the sub-field where the transport of dissolved contaminants via moving groundwater is studied. In contaminant hydrogeology, numerically, fluid flow is solved initially and velocity profile is obtained as an output. Later, this velocity profile is used as an input to the transport aspect and subsequently, the concentration distribution as a function of space and time is deduced.

The first part of getting velocity profile from fluid flow is solved at macroscopic level via Darcy's law, while the later part on transport requires the details at the microscopic scale to get the macroscopic transport properties such as macroscopic dispersion coefficient and dispersivity. As the input for the transport equation is at macroscopic scale, microscopic details will not be captured precisely when solving transport equations. Thus, there is a considerable gap between what is required and what has been considered while characterizing the transport of solutes in the groundwater. Furthermore, this problem gets aggravated while solving multi layered geologic formations. In addition, the heterogeneity increases as the scale of the problem increases. This effect is prominently seen in fractured aquifer, where the concept of differential advection plays an important role in describing the transport of contaminated solutes in a groundwater aquifer. Thus, deducing a reasonable Representative Elementary Volume (REV) itself becomes a challenge in the case of a complex fractured reservoir as the degree of heterogeneity keeps increasing with the scale of the problem; and subsequently, the concept of multiple continua (as against a single continuum) comes into picture. And, ensuring the continuity of the fluid mass fluxes at the interface between any two continua becomes numerically challenging for a complex geological formation.

Having understood the basic limitations and capabilities of Darcy's law, the group is currently dealing with diverse real and challenging problems related to the fluid flow in a complex porous medium. They are extensively using numerical modelling and simulation to understand the underlying physics and predict the real situations.

**Production of methane from Coalbed Methane reservoir:**

Coalbed methane (CBM) is basically the methane ($CH_4$) gas contained within coal***. Characteristics of CBM reservoirs are different from conventional reservoirs in several aspects. Coal is a heterogeneous and anisotropic porous media where two distinct porosity systems can be found: macropores or cleats, and micropores or matrix. The cleats constitute the natural fractures common to all coal seams. The matrix contains the vast majority of the gas. Among the available unconventional energy resources, CBM is the cheapest and easily available resource. It is observed that a thin layer of coalbed can uphold multiple times of methane than its total volume. So, how does the methane production process work?

In CBM reservoir, methane gas is adsorbed on the surface. Now the crucial question is: How does the gas flow during production? Generally, the methane flow in CBM reservoir is complex in nature and it follows three basic steps in production

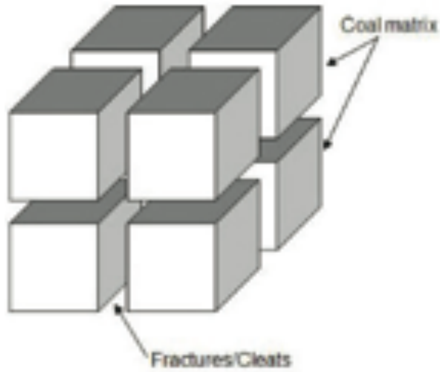


*Fig 2: Schematic of Coal matrix and Fractures*

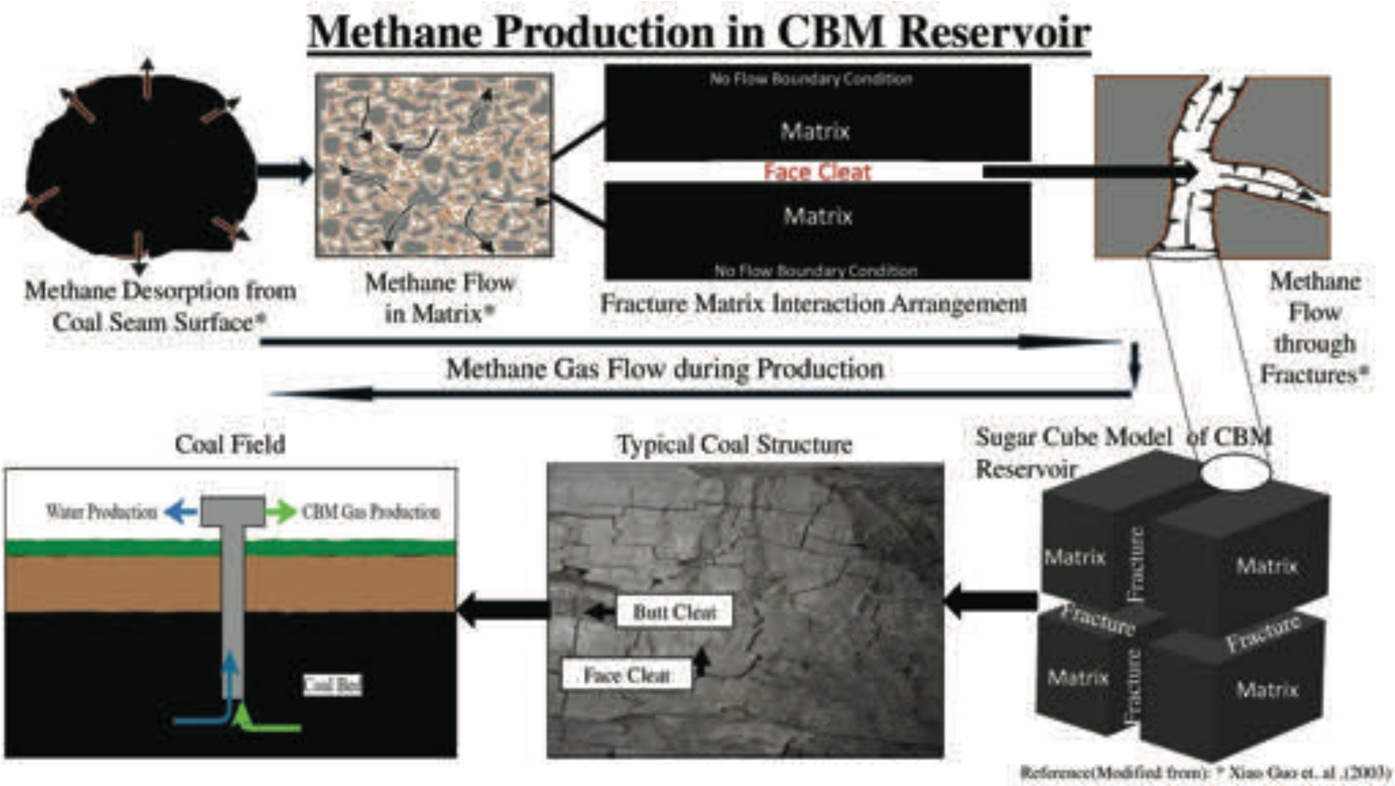


*Fig 3: Schematic of methane production process in Coal Bed Reservoir*

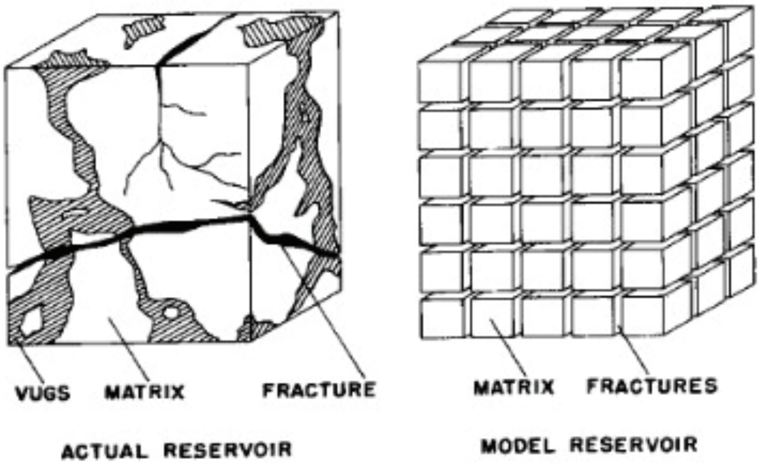


*Fig 4: Sugar cube model of fractured reservoirs [2]*

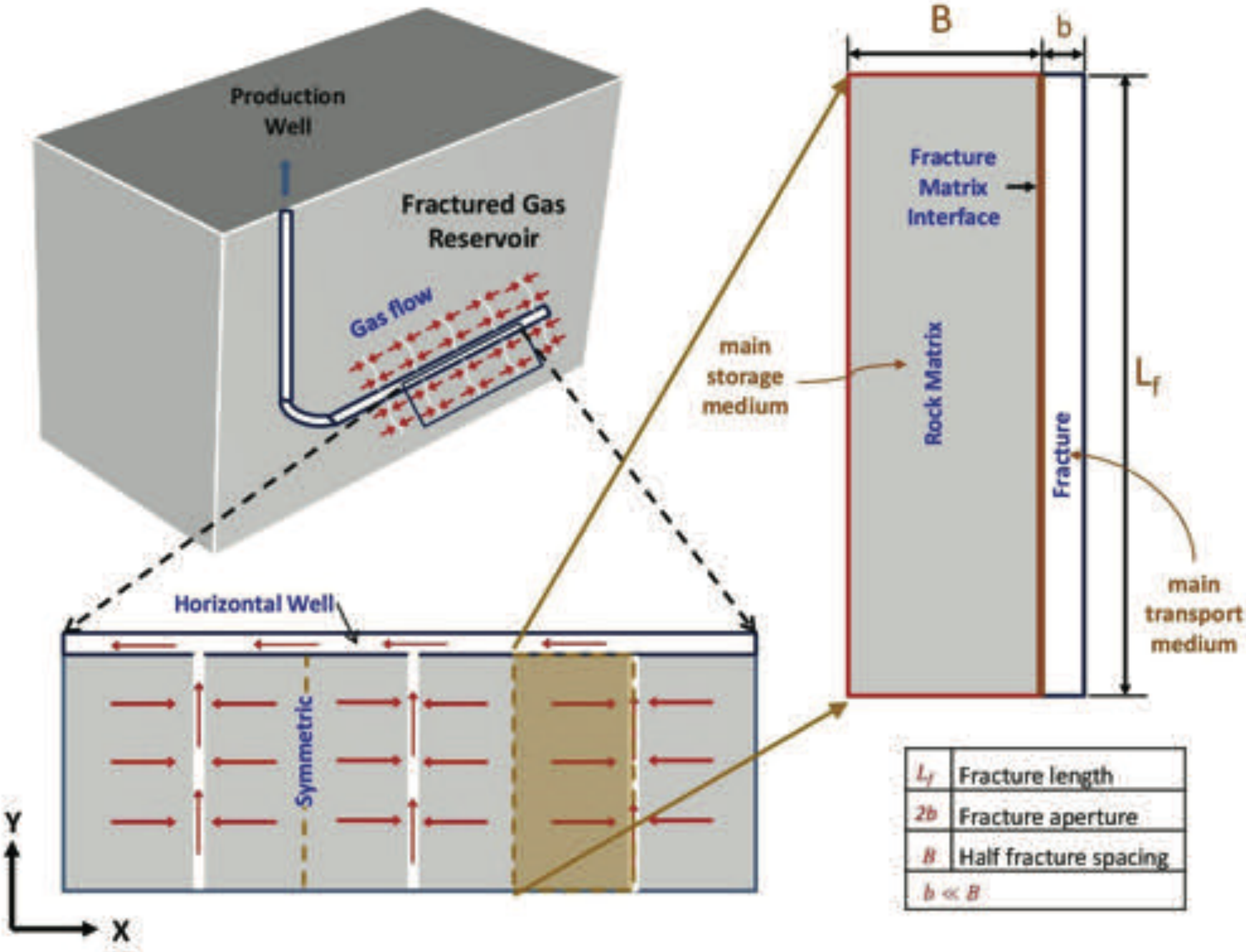


*Fig 5: Schematic of the model for gas flow in fractured reservoir*

which starts from desorption,leading to diffusion and then cleat flow process. Production process starts from the gas desorption. Desorption of methane starts due to the reduction of pressure in the matrix as dewatering happened. After desorption, gas will enter into the matrix system. The pore size of the matrix is so small that the diffusion of free methane in the fracture is concentration dominant instead of pressure dominant. As methane comes in fracture, flow is governed by the pressure difference. During this process, other geo-mechanical changes also occur in coal in terms of stress and dynamic permeability which affect the production rate.

Avanish, a fourth year research scholar who is currently working on the aforementioned project talks enthusiastically how they are numerically probing the process once the methane gas flows through the fractures.

First, to mimic the CBM reservoir a sugar cube model (introduced by Warren and Root (1963)) is employed, where, the cubes are considered as matrix and the remaining voids as fractures. At the next stage, finite volume method (FVM)**** is used to understand the flow behavior of gas and then it is compared to the real scenario of methane production. Thus the numerical approach can unfold the underlying mysteries of the flow behavior of gases in fractured reservoirs and offers a complete understanding of the real problem of methane production process in CBM reservoir which has immense importance in industrial applications.

**Fluid flow through carbonate reservoir:**

Conventionally, sandstone reservoirs that are heterogeneous in nature are treated as a homogeneous reservoir. The reason behind this is that the variation of porosity and permeability in these reservoirs are smooth and continuous in the physical domain. However, the scenario is quite different for fluid flow through the carbonate reservoir which is a fractured reservoir. When fluid flows from fracture to rock-matrix or vice versa in a fractured reservoir, there is a significant variation in the magnitude of porosity and permeability over a very small distance. As a result of this, pressure becomes discontinuous at the fracture-matrix boundary contrary to the homogeneous sandstone reservoir and disrupts the continuity of fluid mass fluxes at the fracture-matrix interface. Thus, a multiple continuum approach must be followed to understand the fluid flow in fractured reservoirs. Abhishek, another research scholar from the group, working on the fluid flow in fractured reservoir, thus developed an innovative modelling approach to tackle the problem. In this approach, the fractured reservoir is modeled as a dual-porosity model which can help to understand fluid flow through the fractured reservoir at the scale of a single fracture. In dual-porosity methodology, the high permeable fracture works as the transport medium and low permeable rock matrix works as a storage medium. As a result, we need to solve fluid flow in both the continuums separately

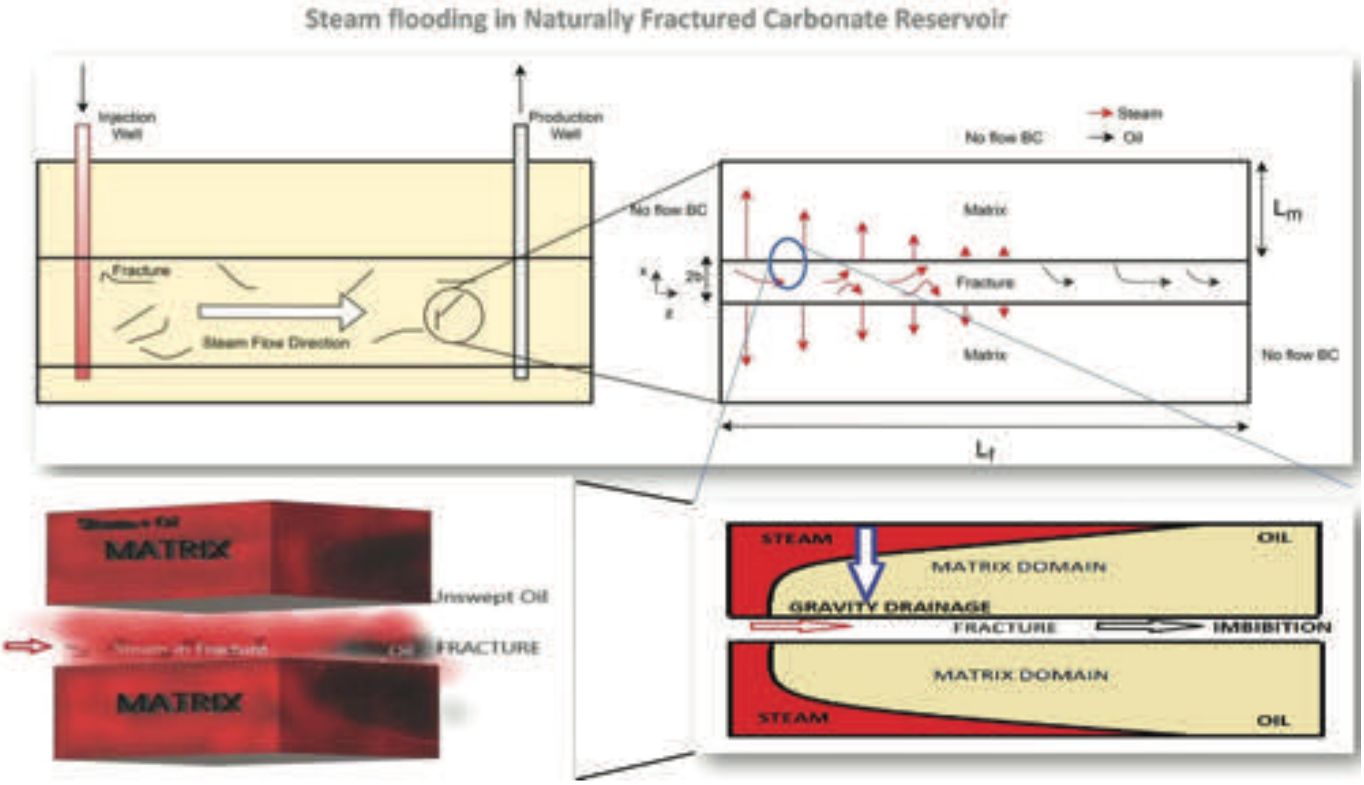


*Fig 6: Schematic of steam flooding in naturally fractured carbonate reservoir.*

and the fracture-matrix interaction is considered by a coupling term at the fracture-matrix boundary. The effect of fracture permeability, matrix permeability and fracture aperture thickness on the fluid flow from the rock-matrix to the fracture are analyzed using the model. A complete insight of the underlying processes are uncovered through this approach which in turn helps to understand any kind of fractured reservoir.

**Steam flooding enhanced oil recovery from fractured carbonate reservoir:**

More than 60% of world's oil and around 40% of gas reserves are present in carbonate reservoirs. The complicated nature of naturally fractured carbonate reservoir is the key reason behind the efforts put by the oil industry to get to know the reservoir better and to model them with reasonable amount of certainty. In this context, steam flooding mechanism emerges as an important method for enhanced oil recovery employed on Naturally Fractured Carbonate Reservoir (NFCR). Shantanu, another research scholar currently working on the numerical modelling of the topic mentioned above, gives us a brief idea of steam flooding mechanism for enhanced oil recovery.

Initially, steam is injected into the naturally fractured carbonate reservoir. Due to high permeability steam flows through the fractures. Then, the steam gradually moves from fracture to the matrix where the oil is stored. Since oil is stored in matrix, the steam that reached there reduces its viscosity and results in an increased mobility which will cause the flow of oil from matrix to fracture. Then, this oil will flow through interconnected fractures and later will be produced from the well.

The diverse fields under the common theme of fluid flow in porous medium thus offer a variety of real world problems which is crucial for so many industrial applications including petroleum, oil and gas industries along with its hydrogeology implications. Prof. Suresh's group, devoted to the numerical modelling to rigorously understand the complex processes and mechanisms happening inside the reservoirs at the macroscopic scale, has managed to extract the physics out of it which is extremely beneficial and important for further development of this field. Their results, predictions and understanding based on numerical models give a solid boost to the community to take up more real and challenging problems to work on.

**Professor's Bio**

Professor. G. Suresh Kumar is currently working as a faculty in the Department of Ocean Engineering, IIT Madras. He has done his Ph.D from Indian Institute of Science (IISc) in 2004. After finishing his Ph.d, he worked as Post-Doctoral Research Fellow at University of North Dakota, Grand Forks, USA between 2003 to 2005 and at Queens University, Kingston, Ontario, Canada from 2005 to 2006. He joined as Assistant Professor at IIT Guwahati in 2006. Later he joined IIT Madras in 2007 in the department of Civil Engineering. In 2010, he finally joined as an Associate professor in the department of Ocean Engineering where he is serving as a Professor from 2015. His central theme of research involves numerical modelling and simulation of fluid flow in fractured reservoirs in a macroscopic scale as against the conventional porous medium.

**Author's Bio**

Kanka is a fifth year research scholar in the Dept.of Physics at IITM. He is working on the the molecular structure and dynamics of fluids. Apart from being an avid reader of non-fictions, a crazy movie-buff, an occasional guitarist and a passionate photographer, he often finds solace in travelling with a "Marquez" or a "Jibonanando" or a "Marx" in hand.

# Labels, Land and Liminality Decoding Tibetan Refugee Identity

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Vidya Muthulakshmi M.

It was early 2014. Another bout of general elections scheduled for mid-2014, saw inflamed passions and heightened tensions across India, as debates about political parties and candidates were flaring up, in public and in private. But unnoticed by most of the country, there was one community in India, that was grappling with something much more fundamental. Judgements issued by the High Courts of Delhi and Karnataka in 2 separate cases of Tibetan individuals seeking an Indian passport could be seen as a trigger to a chain of events that culminated in an Election Commission of India (ECI) directive allowing Tibetan refugees, fulfilling certain conditions, to enroll as voters in the upcoming elections. This directive spurred a complex debate in the Tibetan community about how they identified themselves in India: 60 years into their exile, could they afford to stay on as refugees? Could Tibetans as citizens of India, continue to hold on and work towards the community's struggle for an autonomous Tibet?

Back in insti, this directive had caught the eye of Dr Sonika Gupta, Associate

*Fig 1: Annual prayers at Majnu ka Tilla, a Tibetan settlement in Delhi. Source – Dr. Sonika Gupta*

Professor from the Department of the Humanities and Social Sciences, and one of the professors running the China Studies Center here at IIT Madras. An expert in International Relations with a focus on China and its domestic politics, Dr Sonika Gupta, was piqued by the unique situation faced by the Tibetans. Beginning in 2014, with the final year MA Project of a student, Divya Mary, from the HS department, the research by Dr. Sonika Gupta, over the years, has delved deep into the lives of Tibetans in India, as they went about their daily lives like the rest of the country, while still holding a fire of hope to return to their homeland one day deep in their hearts.

In 1950, at the age of 15, the 14th and current Dalai Lama, took over spiritual and temporal power in the Tibetan Autonomous Province of China. Nine years later, a failed uprising against Chinese oppression of Tibet, saw the His Holiness flee the province to seek refuge in India. Along with him, had arrived thousands of devout Tibetans.

As the Tibetan refugees settled down in transit camps, setup in Assam and West Bengal, Pandit Jawaharlal Nehru, then Prime Minister of India and His Holiness Dalai Lama had the foresight to realize that the refugees might need to stay for an extended period of time away from the "Great Snow Land of Tibet". In the midst of soaring health concerns and unfriendly weather conditions at the transit camps, Pt. Nehru had reached out to the Chief Ministers of all states of India, requesting for tracts of land to be provided for Tibetan settlements. Subsequently, the first and largest

Tibetan settlement was established in Bylakuppe after the Chief Minister of Mysuru (now Karnataka), responded quickly. Today, the over 90,000 strong Tibetan population is spread over 39 settlements in 12 states of the country.

Brimming with Tibetan arts & craft, prayer flags and schools, the Tibetan settlements continue to mirror a world that the refugees yearn for and reimagine, a world they lost in the aftermath of the uprising of 1959. The Tibetan culture has braved the strains of time and "statelessness" that one could attribute to this self-exiled community.

As Tibetans go about their daily life, pursuing education or earning income to sustain themselves, there is one ritual that they follow religiously – the renewal of their RC. This Special RC or Registration Certificate is an identity document issued by the Government of India, that demarcates any holder of the document as a foreigner belonging to Tibet. Tibetans, like any other foreigner staying in India, were thus required to renew their document periodically. Failing to do so, meant potential yet severe punitive repercussions for them, be it losing scholarships, employment, or government benefits, or facing trouble with law and order of the land. However in the minds of several Tibetans, the RC is not just an identity document: it is viewed as an instrument to keep alive their commitment towards the cause of Tibetan autonomy. Thus, when the Tibetan community used to line up every 6 months or once a year, for decades, to renew their RC, they viewed it not only as a burden necessary for survival, but often as a duty one -needs to fulfill for the sake of their homeland.

Intuitively, voting could be viewed as a manifestation of a citizen's right to choose the leaders of their country and government. However, the Election Commission directive released in 2014 allowed Tibetan refugees born between January 1950 and August 1987 in India, to be added to the electoral rolls as per the Citizenship Act. This is since extended to 2004 and will continue to be extended to all Tibetans of voting age born in India.

India is not a signatory to the UN Refugee Conventions. However, the RC provided to Tibetans refer to its holder as a "sharnarthi", literally translating into "a person who seeks refuge". Thus, while India recognizes refugee communities, they are administered as "foreigners" and not refugees. In this context, it could be argued that if a person holds an RC, it would mean that they are foreigners and are not citizens of India. It would seem as if the EC's directive stood in conflict with the RCs issued to Tibetan refugees in the country, including those born in India between 1950 and 1987.

As Dr. Sonika and her team pored over the various contradictions that seemed to define the Tibetan refugee community's status in India, she found that the most appropriate academic way of defining the Tibetans was, as them occupying "liminal spaces". Liminal, as Oxford puts it, is "occupying a position at, or on both sides of, a boundary or a threshold".

Digging into earlier research about the Tibetan community, Dr Sonika found that there was a want of literature by Indian researchers on the political and sociological aspect of the exile community. Most Indian researchers had focused on understanding the Tibetan conflict and community, using the framework of how it could affect Sino-Indian relationship. As Dr. Sonika set about understanding the questions of Tibetan identity and how Tibetans engaged with it, she found political anthropology provided the most fruitful interpretive framework for exploring questions of legal and political belonging in the community.

Funded by the Chiang Ching-Kuo Foundation in Taiwan, the research was conducted broadly at 3 different levels – high level debates, local level implementation issues and responses of the Tibetan community. The high level debates involved recording responses of the various ministries of Government of India and the Central Tibetan Administration (CTA), and the constitutional arguments guiding the entire debate. Local level implementation issues on the other hand, dealt with the issues faced while implementing the directive, for instance in Himachal Pradesh, where over 1000+ Tibetans had enrolled as voters. The most innovative part of the research, however, came from the understanding of the community's response to the situation. Several qualitative methodologies, such as semi-structured interviews, as well as ethnographic tools were employed as Shikha Mahajan, a Delhi-based independent researcher, and Madhura Balasubramaniam, another student from the HS department now working with Dr. Sonika, traveled across the country interacting with the Tibetan refugees in the settlements. They were helped in field work by Tsewang Dorji, a researcher at the Tibet Policy Institute in Dharamshala, who provided invaluable language interpretation from Tibetan to English.

As Dr Sonika points out, it would be too reductionist an approach to say that a few people within the community, support taking up Indian voting rights and citizenship and a few others oppose it. Rather, a broad spectrum of arguments and counter-arguments were observed, with each Tibetan having a different kind of perspective. If some felt that the act of renewing their RC was necessary to retain the zeal of the Tibetan struggle, others felt that the safety net that a citizenship provides, would only encourage Tibetans to undertake a much more proactive role in the struggle. Several others were of the opinion that considering India's generous gestures towards the Tibetan refugee community, obtaining Indian citizenship, is different from that of acquiring citizenships in other nations, and would not weaken the Tibetan struggle at all. The stance taken by the CTA didn't make matters easier, as the CTA while mentioning that it neither encourages nor discourages Tibetans from taking Indian citizenship, was also clear that no Tibetan could hold both an Indian voting card and the RC. Losing the RC would be a very difficult prospect, for other than the emotional value that it holds, an RC is also the gateway for Tibetans to avail government welfare schemes. More importantly, it functions as the key to attend Tibetan schools and institutions and thus, be schooled in the Tibetan culture. Having a passport would


*Fig 2: Identity Certificate and Registration Certificate issued by Government of India*

*Fig 3: Dr. Sonika (second-right) and Madhura (extreme-right) with Nechung, the State Oracle of Tibet. Source – Dr. Sonika Gupta*

remove the tag of "statelessness" associated with Tibetan refugees, making it easier for them to travel internationally, and open up closed avenues of employment, but at the same time, there are concerns within the community that it could potentially distance them from their much revered culture.

As interactions with Tibetans were being recorded and analyzed, another Indian policy kept standing out in the conversations. In late 2014, the Union Government of India, in consultation with the CTA, had released the Tibetan Rehabilitation Policy 2014, which was centered around the land use rights of Tibetans and the access to social welfare schemes for Tibetans. The welfare rights component of the policy, aimed to provide uniform guidelines under which Tibetans could be given access to welfare schemes However, the component covering land use rights of the Tibetan community dealt with a more complex and fundamental issue. Tibetan settlements across the country could be broadly classified into 3 categories:

1. Settlements where there was a formal handover of land to the settlement by the state government and legal paperwork for the same were available.
2. Settlements on land purchased directly by registered Tibetan societies.
3. Spontaneous Tibetan settlements that mushroomed with the tacit approval of the state government but where no legal paperwork was available.

As issues concerning land, fall under the purview of the state governments, land governance varied from state to state. The 2014 policy, thus aimed to provide uniform documents for all Tibetan settlements where there was a formal handover of the land to the CTA. This however, meant that the policy could only address issues pertaining to the 1st category of settlements mentioned, ignoring the 3rd category which are the most vulnerable to legal sanctions. The policy was in part, drafted as a response to an incident in 2013, when the National Green Tribunal had labeled a Tibetan settlement of over 218 families in Himachal Pradesh as "encroachers", despite the fact that they had settled in the forest land with the tacit approval of the state government even before the Forest Conservation Act was passed in 1980.

The policy in 2014, directed state governments to issue a uniform document to legally lease the land to the CTA for a period of 20 years or until the protection offered by the government of India to the Tibetan community was revoked, whichever was earlier. In case of agricultural settlements, Rent Tenancy Certificates could be issued to individual Tibetans, thus providing them with cultivation rights. Following the release of the policy in 2014, about a third of the 12 concerned states have adopted the policy, with only Karnataka and Himachal Pradesh in the process of implementing the adopted policy. In the case of Himachal Pradesh, the state government is preparing its own Tibetan Rehabilitation Policy along the lines of the 2014 central government policy under the same name to streamline the land governance in the state and to resolve the threat faced by the 218 families.

With the community entering into its 60th year of taking asylum in India, voting and land rights are but mundane matters of survival. What continues to occupy a central topic of discussion in the Tibetan community is the dream of returning to their homeland. With Tibet being a distant memory, for those Tibetans-in-exiles who were too young at the time of exodus, or even a place in legends, for those born after it, His Holiness Dalai Lama and Tibetan Buddhism continues to be a strong binding factor for the community.

With an eye on co-opting Tibetan Buddhism and thus, ultimately its followers, China has been trying to undermine the legitimacy of social structures in the religion and conducts activities purportedly in the name of the religion. However, it has not just been the flexing of Chinese soft power that threatens the religion. The infamous case of the 11th Panchen Lama is one example of extreme measures adopted by China in this conflict. Another important figure in Tibetan Buddhism, the legitimate 11th Panchen Lama was chosen by His Holiness Dalai Lama in the year 1995, but had disappeared immediately upon his selection. While his condition continues to remain unknown, the Chinese government had in the meanwhile, selected another child as the Panchen Lama and placed him as a legitimate Tibetan leader, despite opposition from the Tibetan community.

In the midst of this ongoing religious conflict, the Dalai Lama continues to be a central figure as the spiritual leader and holds a reverential position in the minds and hearts of the majority of Tibetans. As the Dalai Lama, however, His Holiness is expected to not just be a spiritual leader but also to be a political and administrative leader for the Tibetan community. Thus, in what must be a singular instance in the history of world, as Dr Sonika notes, the Dalai Lama faced resistance from a few quarters of the Tibetan community, as he pushed for the devolution of political powers vested in his position by the Tibetan culture. In 2011, the Dalai Lama devolved his powers, ensuring a smooth transition to a democratic setup, developed gradually over the years. Seen today as a gift by the Dalai Lama to the Tibetan community, the democratization of Tibetan institutions, were not without problems of its own, with concerns being raised regarding the impact of democratization on the cohesion of the community and the struggle for Tibetan autonomy.

The Central Tibetan Administration, once known as the Tibetan Government-in-exile, has been responsible for the administration of the Tibetan community in exile. Starting as an organization that worked under the guidance of His Holiness Dalai Lama, the first and foremost task the CTA had undertaken was that of settling Tibetans in various countries, providing the settled Tibetans with identity documents, and coordinating with various governments and NGO's to help build a life for the Tibetans outside Tibet, while continuing to push the demand for Tibetan autonomy. Building an entire bureaucratic set-up, the CTA had representatives in each settlement, who were responsible for taking care of the needs and requirements of the settlement and coordinate with the CTA.

In 2016, the world stood by to watch an extraordinary spectacle, as thousands of Tibetan refugees in different parts of the world voted for the 45-member strong Tibetan parliament. A fully fleshed government administering an exiled community spread across the globe, with its own executive, legislature and judiciary, continues to be an unparalleled experiment in democracy, one from which a lot can be indeed be learnt.

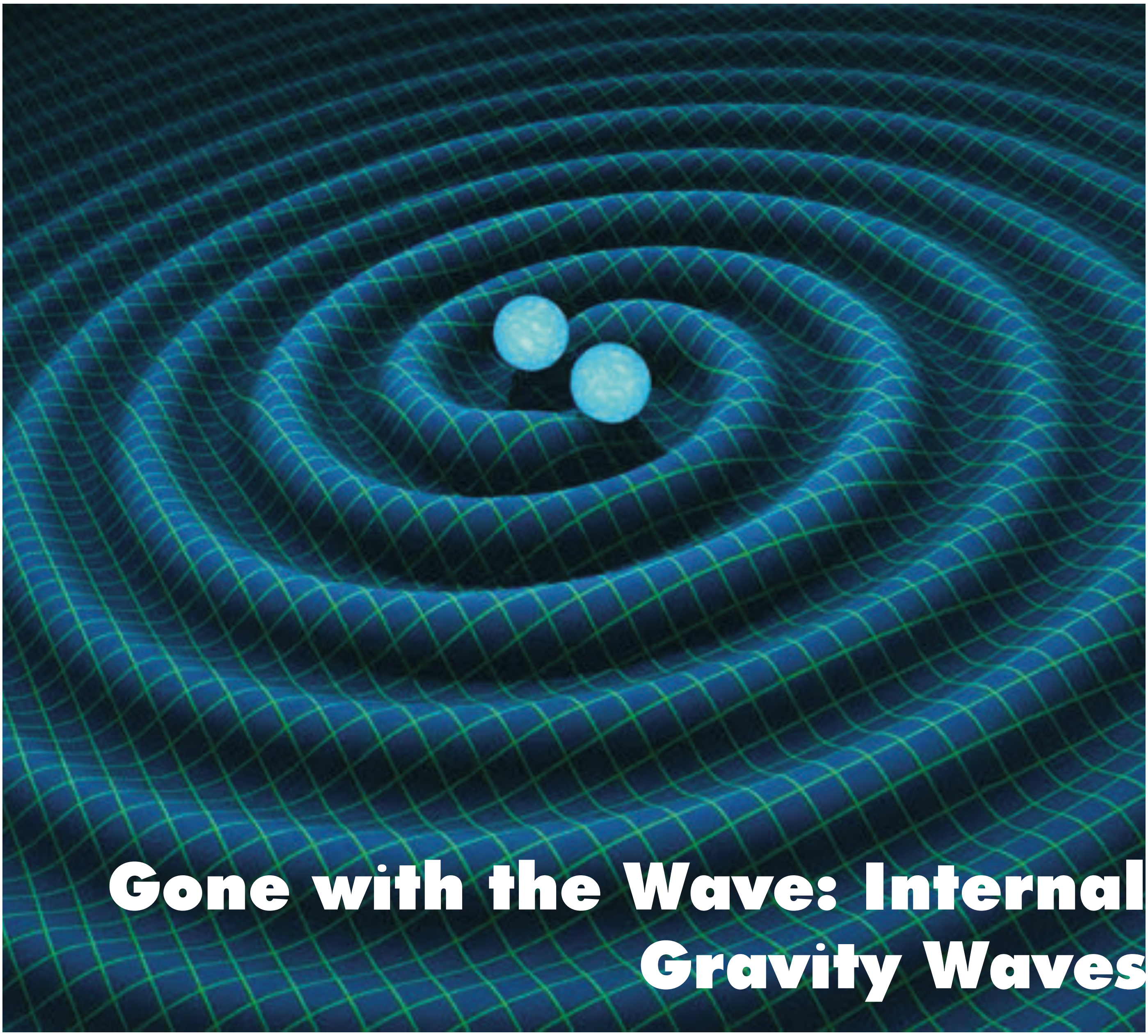
Though the research has been driven by the desire to truly understand this unique community, it would be remiss to not observe the incidental benefits it could have. Considering that the policies in focus have only been around since 2014, quite recent by anthropological terms, the research holds a promising observation of the Tibetan community, even as the policies are implemented. A multi-site study covering almost every major type of settlement in India, the research could serve as a point of information for the CTA, and the Indian government. With the research now moving to the final component of examining the democracy experiment in the exiled Tibetan community, the application of liminal spaces in the understanding of the Tibetan community could indeed be a trailblazinging approach in anthropological circles studying Tibetan refugees.

**Professor's Bio**

Dr. Sonika Gupta is an Associate Professor in the Department of Humanities & Social Sciences at IIT Madras. An alumnus of Presidency College, Kolkata, and Jawaharlal Nehru University, Delhi, Dr Sonika Gupta research interests spans International Relations theory as well as Domestic Politics in China. She was the Founding Coordinator of the China Studies Center, at IIT Madras, that seeks to create an academic center dedicated to long-term study of China in order to develop a dynamic framework for understanding contemporary China and its global role.

**Author's Bio**

With a belief that the combined might of Humanities and Technology, can resolve society's troubles, Ajit, a final year student from the Department of Engineering Design, is currently trying his hand in Economics and Writing. If you don't find him in his friends' room playing the latest Fortnite update or reading stuff, he is either musing about the vast knowledge humans have amassed or he is sleeping.



# Gone with the Wave: Internal Gravity Waves

**Professor**

Dr. Manikandan Mathur

**Writer**

Sharon Christina Tensingh & Malayaja Chutani

**The Invisible Wave**

In the words of the famous physical oceanographers Walter Munk and Carl Wunsch, "without deep mixing, the ocean would turn, within a few thousand years, into a stagnant pool of cold salty water." . But the ocean is definitely not a pool of cold salty water, and instead it is stratified by depth in both salinity and temperature. This means - at different depths in the ocean, salinity and temperature values are not constant, rather their values vary in a nonlinear manner as we traverse the depth of the ocean. This begs the question: what physical processes in the ocean lead to vertical mixing of the water? The Internal Gravity Wave is one such candidate to answer this question.

So, what are Internal Gravity Waves (IGWs) and how do they come to be?

IGWs occur in a the body of a fluid medium which is non-uniform and continuously stratified. The fluid medium can be the ocean, even the atmosphere. Here, we interested

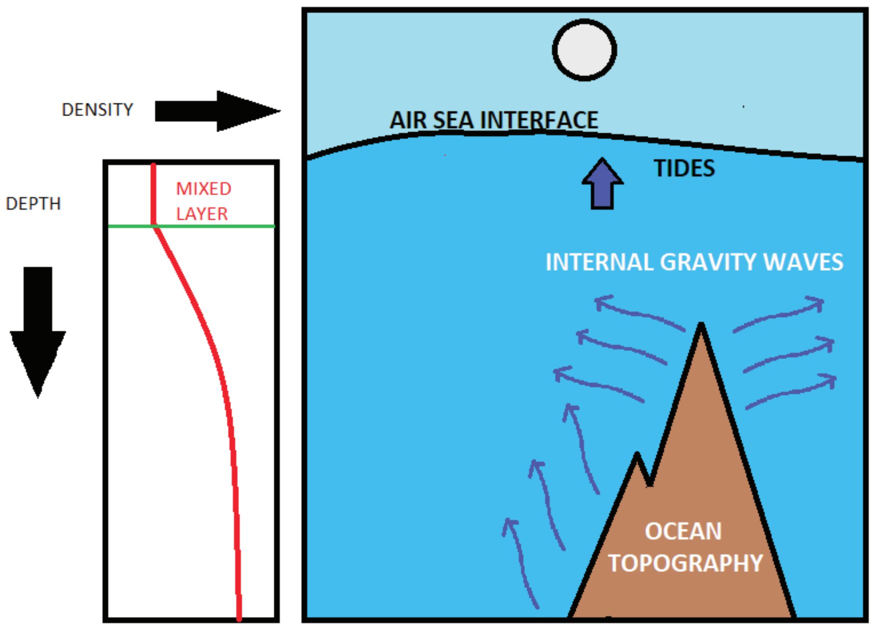



*Fig 1: Generation of Internal Gravity Waves (Image by Sharon Christina Tensingh)*

in IGWs that are generated in the body of the oceans. Unlike surface waves (which are confined to a two-dimensional interface), IGWs can propagate both horizontally and vertically in the body of the fluid. They can be as small as a meter, to as large as thousands of kilometers, and contribute to turbulence and heat transfer in the ocean. Rough topographies in the ocean where IGWs are known to occur are referred to as "IGW hotspots".

Dr Manikandan Mathur, of the Dept of Aero Engg at IIT Madras, has been studying vertical mixing and energy dissipation in the ocean . In this regard, Dr Mathur and his student, Dheeraj Varma, study the role of IGWs, which is "the only serious candidate for vertical mixing", as put by Munk and Wunsch.

**Candidate Mechanism: Wave - Wave Interaction**

It has been established that the mechanical sources contributing to deep ocean mixing are tides interacting with the ocean floor topography, and strong surface winds that create near-surface oscillations which propagate below the sea surface. So, we can safely say that thses are the predominant sources of IGWs. Now, the question is: what mechanisms do IGWs follow to carry out vertical mixing and energy dissipation?

To understand this, Dr Mathur and his team have analytically examined how IGWs interact in a nonlinear manner. They have looked at mechanisms of energy transfer from one length scale to another i.e. waves at longer wavelengths to waves at shorter wavelengths, as they interact with each other. Such questions are routinely asked in problems related to turbulence and deep-sea mixing, mentions Dheeraj. But, the majority of those studies (dealing with energy transfer) work with fluids having a linear density profile. An accurate representation of the ocean, however, requires the consideration of a nonlinear density profile.

When studying or modeling fluid motion of any kind, scientists have to engage with a set of nonlinear partial differential equations - the Navier-Stokes equations - which are solved to obtain possible fluid velocity. The Navier-Stokes equations are basically Newton's second law of motion for fluids. These equations admit only a limited number of analytical solutions, and are therefore are often solved numerically.

The theory of Dr Mathur and Dheeraj's work also starts with the Navier-Stokes equations, with appropriate parameters and boundary conditions. They must now look for admissible solutions to these given conditions, in the context of studying energy transfer from larger to smaller length scales.

As a candidate mechanism for vertical mixing in the ocean, Dr Mathur and Dheeraj study wave-wave interactions in stratified fluid. They state that the transfer of energy to higher modes (i.e. shorter spatial scales) is known to cause instabilities and mixing, but in what way do IGWs dissipate energy is not well understood.

They explain to us that a well-known instability mechanism in IGWs is called the resonant triad interaction. Hypothetically speaking, if we were to consider a uniformly stratified fluid, extending infinitely horizontally and vertically, then three interacting internal waves satisfying the relations $\omega_{1} + \omega_{2} + \omega_{3} = 0$ and $k_{1} + k_{2} + k_{3} = 0$ form, what is called, a resonant triad. Here $k1,2,3$ are the wave vectors and $\omega 1,2,3$ are the corresponding frequencies.

But recall that the ocean is non-uniformly stratified, and of finite extent. And scientists do not know of a simple analytical criterion for a resonant wave triad. As part of their work, Dr Mathur and Dheeraj show the existence of resonant triads and identify the conditions for their existence. This study has led to a publication in Journal of Fluid Mechanics in July 2017.

**The Experimental Set-up**

Dr Mathur's lab has set up an interesting experiment to study and validate their analytical work on how IGWs transfer energy in a stratified density fluid medium. This experiment aims to recreate how different modes (or frequency) of IGWs interact in the ocean's stratified conditions.

The experimental setup consists of a large glass tank (approx. 5m x 0.5m x 1m) and two large buckets (each approx. 1.5m x 1m x 1m). The entire experimental setup stands tall at roughly 2 meters. One of the buckets is for freshwater, and the other is for salt water. Using, what is called, the "double bucket method", a stratified density gradient is created in the tank, over the course of few hours. First, water from the fresh water bucket is pumped into the base of the tank. Then, salt water is pumped into the fresh water bucket at a controlled flow rate, while water from the fresh water bucket continues to be pumped into the base of the glass tank. The idea is to create a stable salinity stratification such that light fluid is on top of

*Fig 2: The experimental setup*

heavy fluid. Dheeraj informs us that such a stratification profile can last for about about a week. To check if the density gradient in the tank is a reasonable representation of the ocean density profile, a Conductivity Temperature Density (CTD) probe will be employed to take a vertical profile of the tank's density gradient.

Now, things get turned on their head! The structure that will mimic the ocean floor topography will be inverted, and placed on top of the glass tank. Subsequently, in order to simulate the relative motion between the ocean floor topography and the ocean water, the inverted ocean floor is moved in a seesaw motion at a specific frequency. The aim is to mimic the relative motion between stratified fluid and the ocean topography due to tides.

The idea is that the moving ocean floor will excite particular range of modes. This means waves of certain frequencies will be set up in the water. Dr Mathur and Dheeraj can pick up which modes are excited by using particle-image velocimetry - measuring velocity fields throughout the tank. The velocity fields will give them an idea of the energy distribution in the tank, once the oscillations are set up. They believe that according to the triad mechanism, only certain modes will be excited, and thus picked up. Through these experiments, the team wants to verify the theoretical mechanism they have previously proposed for how IGWs contribute to the transfer of energy at different length scales. The most challenging part of this experiment is to set up the proper stratification and generating the waves that they want.

Dheeraj tells us that very few people work in such fundamental problems of ocean dynamics, and this novelty excites him. Similar experimental setups exist in other parts of the world, but they are used to look at problems like fluid-structure interaction or how objects move in stratified fluids, and not to study IGWs. Dr. Mathur and Dheeraj have put in a lot of time and effort into getting the experimental setup in place, and they are now excited to begin the actual experiments. According to Dheeraj, this setup will be useful for many other future studies as well.

### The Big Picture

The empirical part of this project is performed on the Bay of Bengal (nicknamed BoB). It may not be the largest mass of sea on the Earth, but it has the largest per capita impact, because the ocean and atmospheric processes due to different energy transfer mechanisms in and above BoB affect a very large population of people. BoB has another unique property: the presence of a thin freshwater surface layer of differential density, of the order of about 10 meters. This layer is formed by annual precipitation and water from several rivers draining into it.

Dr Mathur and his research scholars are part of a much bigger project called the "Coupled Processes in the Bay of Bengal and Monsoon air-sea circulation", which is a collaborative effort between scientists from India and United States of America. According to Dr Mathur, the team works to complement each other's effort, and is highly interdisciplinary, with researchers from various academic backgrounds. Dr Mathur jokes about feeling puzzled when it comes to choosing a category to put himself into, but finally calls himself a fluid dynamicist.

A natural question about Dr Mathur and Dheeraj's work on studying IGWs is how it fits into the "big picture" of the project. Dr Mathur tells us that the main aim is to improve accuracy of existing atmospheric and ocean models, which are used to study the dynamics of the atmosphere. An important input for these models is to know the exact boundary condition at the ocean surface. This means that it is important to know the temperature distribution and the heat fluxes at this air-sea boundary. The aim of Dr Mathur's project is to nudge others in the direction of what contributes to the state of the ocean surface. The wave-wave interaction that they study, results in the local dissipation of energy. This local dissipation could change the temperature at the air-sea boundary. Work is sparse in the area of coupled air-sea interaction as of now. There are individual experts working in climate sciences working on climate and cloud modeling, monsoon forecasts etc. Then there are a separate set of people working on ocean sciences and on various processes in the ocean that affect the fluxes etc. The aim of the project to collaborate, in the hope of moving towards uncharted territories. At the end of our discussion, they caution us about sensationalizing projects of this nature. They tell us that climate modeling and weather forecasting is a distant goal, but shouldn't take away from the strides scientists make in fundamental research being carried out in their fields.

Dr Mathur explains that his part in this collaborative effort is only a small step in understanding wave-wave interaction in a stratified fluid media. He says that the project is expected to end by 2018, but hopes that this would create awareness among researchers and spur them towards looking into energy transfer mechanisms and stratified fluid dynamics.

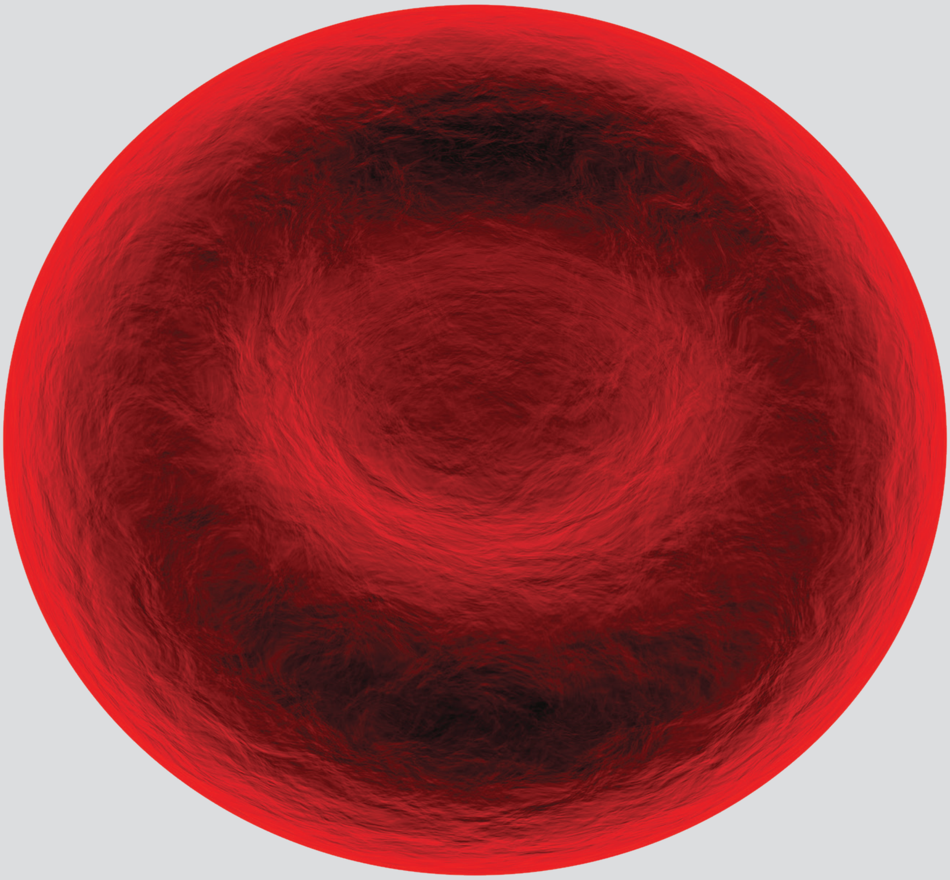
**Professor's Bio**

"Dr.Manikandan Mathur is an Associate Professor in the Dept. of Aerospace Engineering at IIT Madras. He obtained his PhD from Massachusetts Institute of Technology, Cambridge. His research interests span various aspects of fluid flows occurring in geophysical settings i.e. the atmosphere and the ocean, such as: Internal Gravity Waves, Bistability in Geophysical Flows, Stability of Vortices and Lagrangian Coherent Structures.

**Author's Bio**

Sharon is pursuing her PhD in finance from the Department of Management Studies, IIT Madras. She picked finance after engineering as it's surprisingly interdisciplinary & works on market liquidity. She invests her time in activities where learning and fun is balanced. She enjoys reading fiction, listening to music & is part of the institute's basketball team.

Malayaja is a research scholar in the Physics Department, and her broad area of interest is Dynamical Systems. When not working, she likes to read, listen to music, and watch YouTube edutainment channels. She also likes to eat massive quantites chaat, drink caffeinated beverages, and punctuate her surroundings with the Oxford comma.



# Diabetic Wound Healing

**Professor**

Dr. Vignesh Muthuvijayan

**Writer**

Pratyasha Priyadarshini

**Editor**

Ranjani Srinivasan

Over the last few decades, surges in lifestyle diseases have caused panic among people, and rightly so. Diabetes is no stranger in today's world - people from every walk of life are affected by it. According to a recent report, more than 422 million people are affected by it all over the world.

What exactly is Diabetes? Diabetes is a group of diseases that hamper the body's ability to process glucose in the blood over a prolonged period. In simple words, to absorb the carbohydrates in food, especially glucose, the body needs insulin released by the pancreas. This seemingly simple process does not work properly for diabetic patients. This further leads to a weak immune system and causes a string of health issues, such as blindness, kidney failure, amputations, heart diseases and stroke.

One of the common problems that diabetic patients suffer from is delayed wound healing. Whenever there is a wound in our body, healthy cells act on the wound site to promote the healing process.

For non-diabetic people, the regeneration can happen naturally. Hence, simple treatments such as regular bandage and ointments are sufficient. The point to note here is that these bandages and ointments are primarily used to prevent and treat infections. They do not play any direct role in enhancing the healing process. In diabetes, hyperglycemia or high blood sugar is the chief reason behind delayed or impaired wound healing. It increases the risk of foot ulcer, which is very difficult to treat and may lead to amputation.

The wound healing process has distinct systematic phases namely hemostasis, inflammation, proliferation, and remodeling. During inflammation, macrophages and neutrophils are recruited for cleaning the pathogenic contamination. However, the inflammation in diabetic wounds is prolonged leading to defective phagocytosis, enhanced release of proinflammatory cytokines and matrix metalloproteinases (MMPs). Nitric oxide (NO) plays a major role in the activation of fibroblasts, and keratinocytes, and neovascularization. But, hyperglycemia-induced reactive oxygen species (ROS) reduce the NO level at the wound site, which, in turn, affects the proliferative phase of diabetic wound healing. The proliferative phase of wound healing accounts for collagen synthesis and formation of new blood vessels. Formation of granulation tissue, wound contraction, and re-epithelialization also occur during this phase. It is thus essential for the vascular network to be recovered early to prevent wound expansion and ulceration in diabetic wounds.

Prof. Vignesh Muthuvijayan and his research group in the Department of Biotechnology are trying to prepare a material that will accelerate the process of healing. There are more than 100 different factors that have been identified to influence diabetic wound healing. Amongst these factors, Prof. Vignesh and his team are targeting to address five key factors. Four of them help in accelerating the healing process, and the last one is to prevent any infection that would cause a delay in healing or other complications. To address these factors, bioactive moieties with desired properties, which target certain aspects that are specifically impaired in diabetic healing, are chosen. As merely applying these bioactive moieties to the wound would not be the best way of treatment, Prof. Vignesh and his team work on developing a type of bandage material (scaffold or hydrogel) in which these moieties could be loaded. In addition to delivering these bioactive components, the material could also help in absorbing the wound exudates (the liquid coming out of the wound) and provide a moist environment that is conducive for healing. These bioactive moieties present in the patches are expected to leave the bandage material, go into the body, and trigger biological responses that are desirable in activating the healing process.

As impaired collagen deposition in diabetic wounds is one of the major reasons for delayed healing, it is necessary to focus on a material that will help in improving collagen production. Collagen is the protein present in the extracellular matrix (ECM) all over the body on which the cells can attach and grow. Improved collagen deposition should lead to faster healing. Then, the next aspect desirable to be improved is vascularization or angiogenesis. This process of blood vessel formation is significantly slower in diabetic healing. By addressing this limitation, the blood vessels that are formed will help in the healing process. As inflammation is a prolonged phase in diabetic healing, anti-inflammatory molecules are required to ensure that this phase is shortened. The final requirement is the antioxidant property, which can address the increased levels of Reactive Oxygen Species (ROS) and other reactive species at the diabetic wound sites. As these reactive species can cause complications in the healing process, it is desirable to remove them using antioxidant molecules. Last but not least, the antimicrobial property is a must have to prevent infections. Prof. Vignesh and his team have identified these biological activities are required in an effective wound dressing material.

To provide these desirable bioactivities, Prof. Vignesh and his team have identified different bioactive moieties that have to be delivered to the site using a dressing. The dressing material suited for this application needs to be a polymer. The team in Prof. Vignesh's lab have been working on quite a few polymers that are biocompatible (i.e., compatible to the tissue where the material is being used and not cause any complications). Another desirable property is , the ability to absorb the wound exudates, to maintain a moist environment so that the wound can heal better. At the same time, it should also prevent all the enzymes in the matrix metalloproteinases which degrade the matrix being formed. A material with good absorption property can remove these enzymes. In addition to this, the material needs to help in cell attachment, so that more cells can adhere and help in the healing process.

On top of the desired biological properties, Prof. Vignesh and his team focus on using inexpensive materials for imparting these bioactivities. The cost of the final product is probably the most important factor. Currently, some bioactive materials that can accelerate the wound healing process are commercially available. However, these are prohibitively expensive (cost in thousands of dollars). As the dressing material needs to be regularly replaced, they are not affordable for most of the patients in India. The group's approach has been primarily with inexpensive materials, because they are determined to make the product available to the consumers and at that time, it shouldn't become prohibitively expensive. The lacuna in the field is not about the science itself, but about the economic aspect. Thus Prof. Vignesh emphasizes desirable bioactivity, but with low cost.

Based on this, the research team identified three carbohydrate polymers that have the desired base material properties, viz. chitosan, konjac glucomannan, and isabgol (psyllium). For each of the bioactivity, the team has worked on different molecules and identified molecules that are effective individually. The focus eventually shifts to identifying the optimal combination so that there can be a multi-pronged approach towards treating diabetic wounds. In case of materials with more than

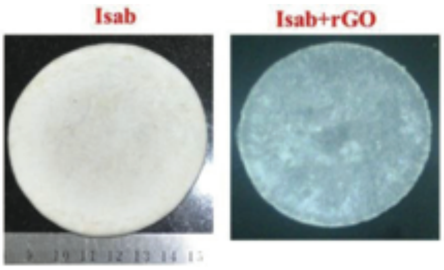



*Fig 1: isabgol+rGO*

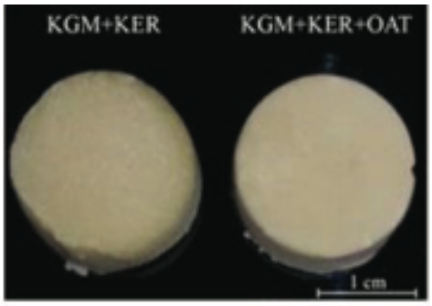



*Fig 2: glucomannan+keratin+oat*

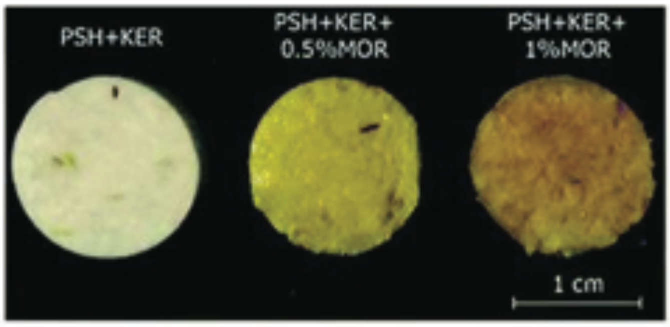



*Fig 3: psyllium+keratin+morin*

one bioactivity, potentially there can be an additive or a synergistic effect on the healing process. Currently, the trials are being done on diabetic rats. Prof. Vignesh's group aims to take it to clinical trials in the near future.

Prof. Vignesh and the research group have explored various materials for each bioactivity. With respect to collagen deposition, they have made use of glutamic acid, which is an amino acid precursor for collagen production. When it comes to angiogenesis (blood vessel formation), they have experimented with graphene oxide and reduced graphene oxide, which are graphene-based nanoparticles shown to improve angiogenesis. The graphene oxide (GO) was synthesized using a modified Hummers' method and rapidly reduced under focused solar radiation to get reduced Graphene Oxide (rGO). Ethanolic oat extracts, rich in vitamin E, are dermo-protective, anti-inflammatory as well as antioxidant. Morin is a plant-derived avonol notable for its antioxidant activity against lipid peroxidation. To improve the cell attachment on the base carbohydrate polymers, they have used keratin (a protein common in human hair), which is biocompatible biodegradable, and rich in cell adhesion sites. To impart prolonged antimicrobial property, the team is

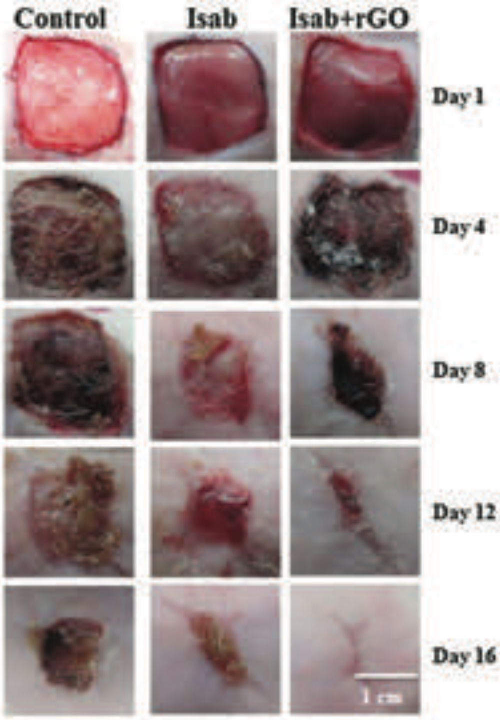



*Fig 4: [1]*

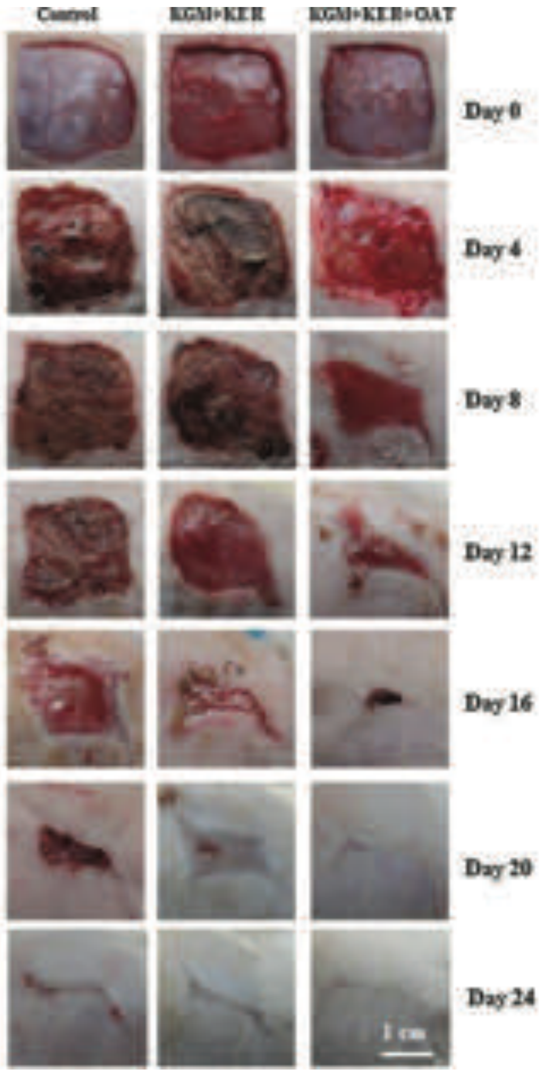



*Fig 5: [2]*

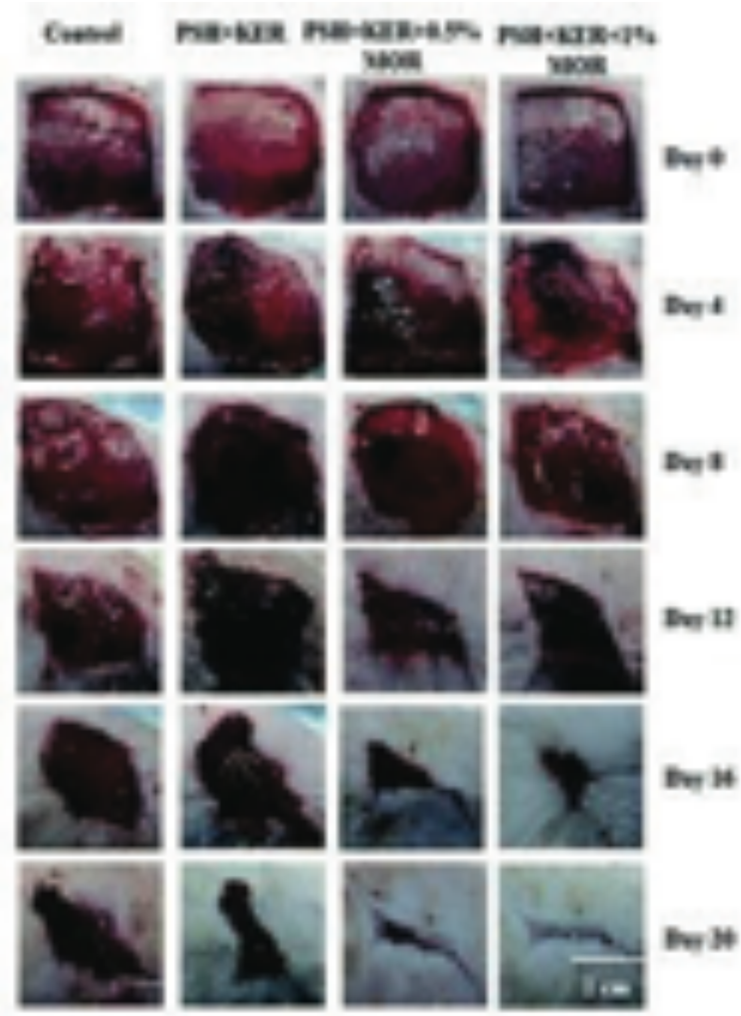



*Fig 6: [3]*

*Fig 4-6: The progress of wound closure over time* currently working on modifying the base carbohydrate. Thus, the group has prepared hydrogel scaffolds with combinations of isabgol+rGO, psyllium+keratin+morin and glucomannan+keratin+oat.

All these samples have been tested on male Wistar rats procured with due permission from Institutional Animal Ethics Committee (IAEC) and Institutional Animal Care and Use Committee. Diabetes was induced in the rats, and subsequently, wounds were created in the dorsal region after anesthetizing the animals. The diabetic rats were divided into groups where the first group was treated with non-medicated cotton gauze and the later ones with different combinations of the materials mentioned above. These animal studies, which were performed at CSIR-CLRI with the help Dr. L Suguna, clearly show that the diabetic wounds treated with the dressing materials developed in Prof. Vignesh's laboratory significantly improved the healing process.

At a time when the present generation is struggling to cope with the pressure of ever-changing lifestyle issues, diabetes is certainly a disease that cannot be ignored. Delayed wound healing leading to foot ulcer and then amputation is one of the most dangerous outcomes of this disease. Effective and inexpensive dressing materials are indeed the need of the hour. Prof. Vignesh and his group have taken the lead in addressing it. These researchers are working towards turning the dream of acquiring affordable commercial dressing material into reality.

**Professor's Bio**

Dr. Vignesh Muthuvijayan is working as Assistant Professor in the Department of Biotechnology at IIT Madras since October 2011. He has Master's degree in Chemical and Biochemical Engineering from University of Maryland, Baltimore County and PhD in Chemical Engineering from Oklahoma State University. He has worked as a postdoctoral fellow at Johns Hopkins University. His research interests are in the area of biomaterials and their applications.

**Author's Bio**

Pratyasha is a research scholar in the Department of EE (RF and Photonics). She enjoys the world of silicon during the daytime and night brings in all the curiosity of "what's out there" to her. For her, platform 93/4 opens to the world of technology. Books,movies and music are her constant companions.

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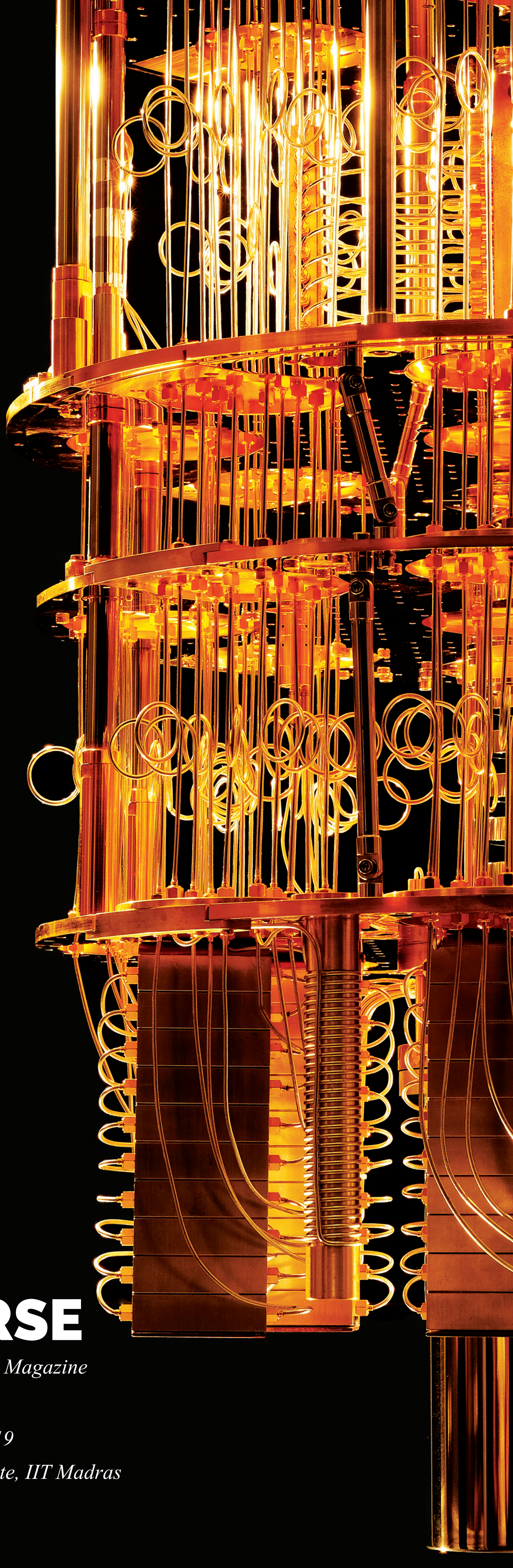

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