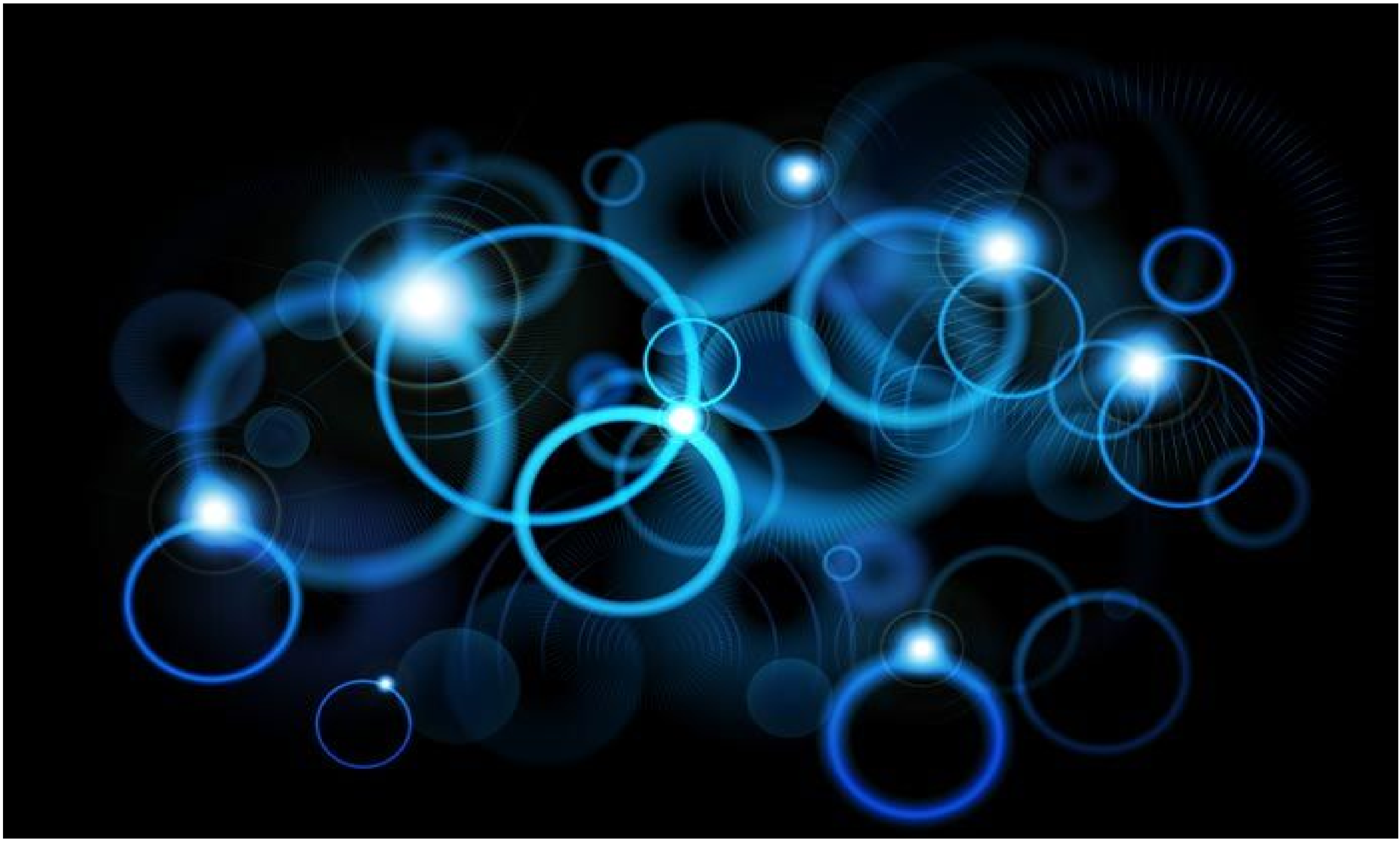
Sensors and Control - MEC 320 T

Optical Gas sensor using Inverse Opal SiO2 Photonic Crystals

Business Proposal – A novel idea



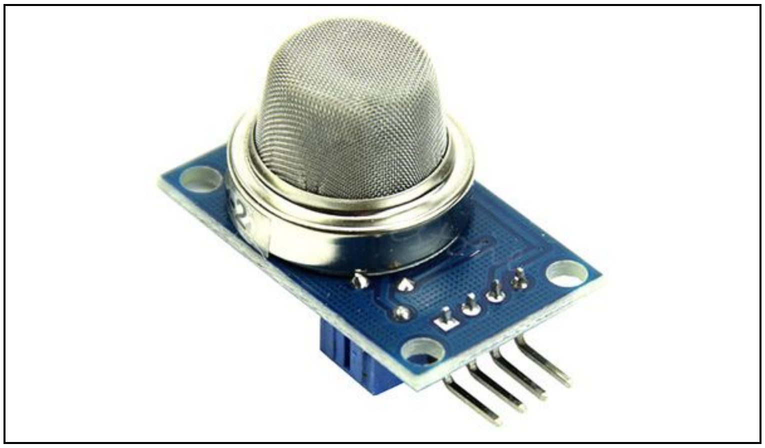
Introduction:

India’s gas sensors market is expected to grow to USD 0.12 billion by 2021 at a CAGR of 4.86% over the period 2016-2021. The proliferation of handheld devices has led to developments in the field of smart gas sensors considerably widening their application scope. The need for ensuring safety in workplaces is expected to be the key driving force for the market over the next six years.

The major trend driving India’s gas sensors market is the development of wireless capabilities and miniaturization coupled with improved communication capabilities, which enables their integration into various devices and machines without compromising the detection of toxic or flammable gases at safe distances. India accounted for about 16% of the Asia-Pacific market in 2014, and is expected to be the third largest segment by the end of the forecast period, mainly due to advancements in sensor technologies in the region.

India’s gas sensors market is segmented on the basis of type (oxygen sensors, carbon dioxide sensors, carbon monoxide sensors, nox sensors, and others), technology (electrochemical sensors, semiconductor sensors, solid state/MOS, PID, catalytic, and IR), and industry (medical, building automation, environmental, petrochemical, automotive, industrial, and others).

What are Gas sensors?



Gas sensors (also known as gas detectors) are electronic devices that detect and identify different types of gases. They are commonly used to detect toxic or explosive gasses and measure gas concentration. Gas sensors are employed in factories and manufacturing facilities to identify gas leaks, and to detect smoke and carbon monoxide in homes. Gas sensors vary widely in size (portable and fixed), range, and sensing ability. They are often part of a larger embedded system, such as hazmat and security systems, and they are normally connected to an audible alarm or interface.

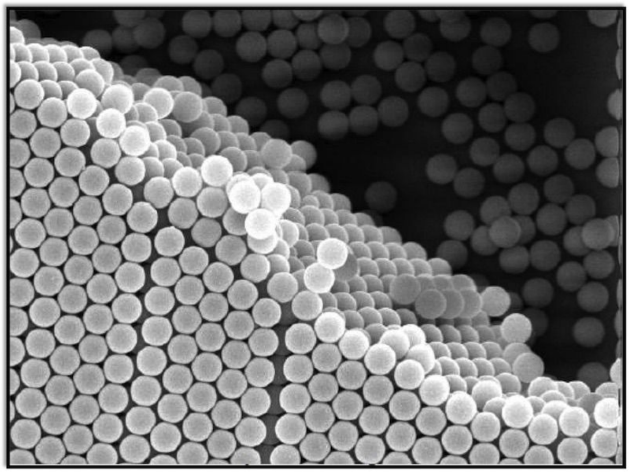
Based on the concentration of the gas the sensor produces a corresponding potential difference by changing the resistance of the material inside the sensor, which can be measured as output voltage. Based on this voltage value the type and concentration of the gas can be estimated.

Types of Gas Sensors:

- Metal Oxide based gas Sensor
- Optical gas Sensor
- Electrochemical gas Sensor
- Capacitance-based gas Sensor
- Calorimetric gas Sensor
- Acoustic based gas Sensor

Proposed Sensor:

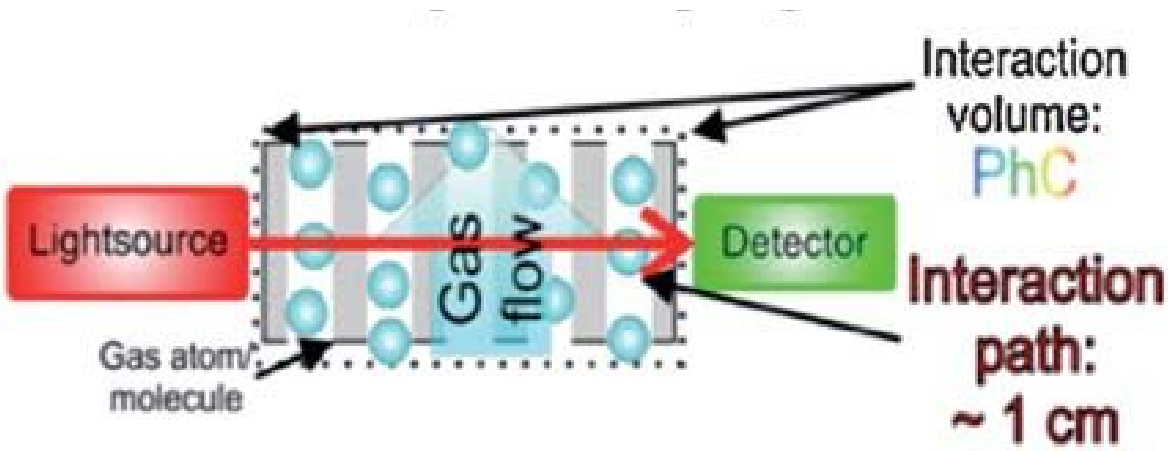
The proposed sensor works using **Inverse Opal structured Sio2 Photonic Crystals**. Photonic crystals(**PhCs**), periodically arranged monodisperse nanoparticles, have emerged as one of the most promising materials for light manipulation because of their photonic band gaps (PBGs), which affect photons in a manner similar to the effect of semiconductor energy band gaps on electrons.



PhCs are materials that possess periodicity in the dielectric constant. These materials can affect the motion of photons in a similar way that a semiconductor crystal affects the motion of electrons. The periodic arrangement of the dielectric materials within the PhCs will produce a photonic band gap (PBG).
Light of certain wavelengths or frequencies located in the PBG is forbidden to propagate through the PhCs while other light is allowed to travel.

The light emitted by the source gets refracted by the Gas present in the atmosphere and this incident light ,on the surface inverse opal SiO_2 structure , increases the energy of the photons and emits a color based on the photonic band gap of the Inverse Opal SiO_2.When light propagates through PhCs consisting of periodic variation of the dielectric constant, the incident light with a certain wavelength that matches the PBG will be reflected.When the reflection peak is located in the visible region, PhCs will show bright colors. This Color change is calculated by the arduino cum light receiver. This change in color tells the gas present or incident on the Crystal.

BLOCK DIAGRAM OF THE PROPOSED SENSOR



The use of PhCs to replace the interaction volume in a conventional optical sensor can obtain compact, robust and low-cost gas sensors, as shown in the figure. Due to the low group velocity mode, the interaction of light and gas within the interaction volume composed of PhCs is enhanced and the interaction path is effectively reduced.The size of such a PhC-based optical gas sensor can be reduced to less than 1 cm, which is less than an order of magnitude improvement in volume as compared to conventional optical gas sensors. Therefore,PhCs provide a useful platform for portable and remote sensing because of their small volume and sharp spectral features,which can be probed using low power laser probes.

As the surface area of the crystal is high, the adsorption would be high which in turn increases the sensitivity of the sensor. The range of the sensor, for increased sensitivity, would be 10 to 50 cm.

About Photonic Crystals:

The periodic arrangements of dielectric materials within the PhCs can produce a PBG. The propagation of light with the wavelength located in their PBGs is forbidden, thus diffraction of such light will be observed, which exhibits a brilliant structural color. The diffraction properties of the PhCs can be described by Bragg's law:

$$m\lambda = 2nd\sin\theta$$

Where

- m is the diffraction order,
- λ is the wavelength of incident light,
- n is the effective refractive index of the periodic structure,
- d is the spacing between the planes in lattice,
- θ is the glancing angle between the incident light and diffraction crystal planes.

It can be inferred that the centre wavelength of the reflection peak, at normal incidence of the light, depends on the spacing between the planes in lattice (d) and the effective refractive index of the periodic structure (n).

The average refractive index of the photonic nanoarchitectures takes the average value of the refractive indices of all their components, which can be approximately calculated by the following law:

$$n_{\text{eff}}{}^2 = \sum n_i{}^2 V_i$$

where n i and V i are the refractive index and the volume fraction, respectively, of the individual components (i) of which the photonic materials are composed.

The effective refractive index (n) increases when the air inside the void space of the PhCs is replaced by a vapor compound with higher refractive index, which would cause a shift of the Bragg peak to longer wavelengths. A similar effect will occur if the lattice constant of the PhCs (d) is increased due to the swelling of the vapor. These are the main optical sensing mechanisms of the PhCs for the gas/vapor compound.

From above relations, PhCs can also be used to enhance the intensity of the excitation light or fluorescence with the wavelength located into their PBGs and thus ***improve the sensitivity of gas sensing.***

The current competitors are conventional Gas sensors manufacturers.

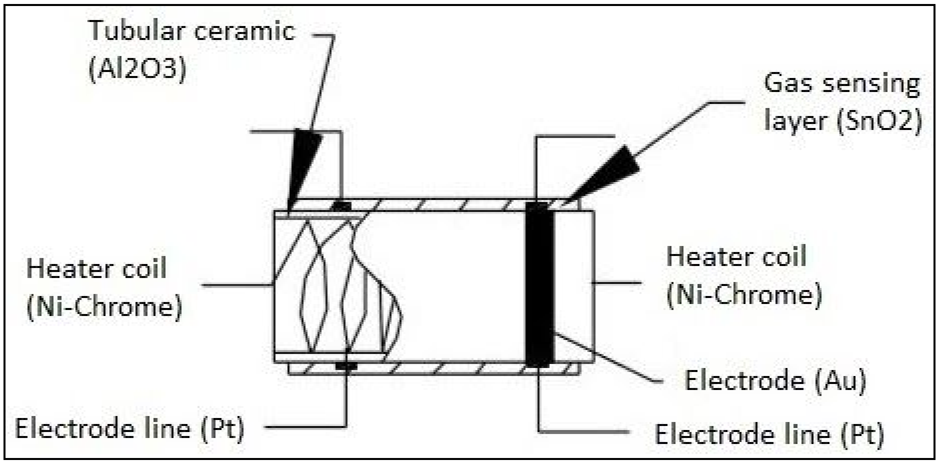
The limitations for the conventional gas sensors are limited Temperature range, Short limited shelf life, Cross-sensitivity and Short Life Span.

Working of the Gas Sensor:

All Gas sensors will consist of a sensing element which comprises the following parts.

1. Gas sensing layer
2. Heater Coil
3. Electrode line
4. Tubular ceramic
5. Electrode

The below image illustrates the parts present in a metal oxide gas sensor:



One of the most commonly used gas sensors for toxic identification and smoke detection is the metal oxide based gas sensor. This type of sensor employs a chemiresistor which comes in contact and reacts with target gasses. Metal oxide gas sensors increase their electrical resistance as they come into contact with gasses such as carbon monoxide, hydrogen, methane, and butane. Most home based smoke detection systems are oxide based sensors.

The purpose of each of these elements is as below:

Gas sensing layer: It is the main component in the sensor which can be used to sense the variation in the concentration of the gases and generate the change in electrical resistance. The gas sensing layer is basically a chemiresistor which changes its resistance value based on the

The concentration of particular gas in the environment. Here the sensing element is made up of a Tin Dioxide (SnO_2) which, in general, has excess electrons (donor element). So whenever toxic gases are being detected the resistance of the element changes and the current flown through it varies which represents the change in concentration of the gases.

Heater coil: The purpose of the heater coil is to burn-in the sensing element so that the sensitivity and efficiency of the sensing element increases. It is made of Nickel-Chromium which has a high melting point so that it can stay heated up without getting melted.

Electrode line: As the sensing element produces a very small current when the gas is detected it is more important to maintain the efficiency of carrying those small currents. So Platinum wires come into play where it helps in moving the electrons efficiently.

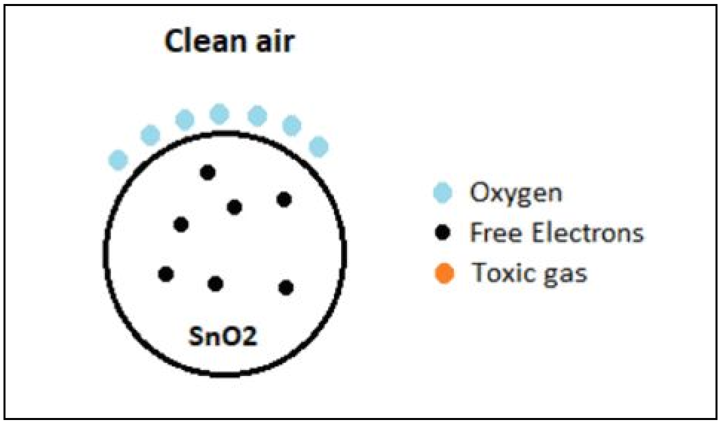
Electrode: It is a junction where the output of the sensing layer is connected to the Electrode line. So that the output current can flow to the required terminal. An electrode here is made of Gold (Au –Aurum) which is a very good conductor.

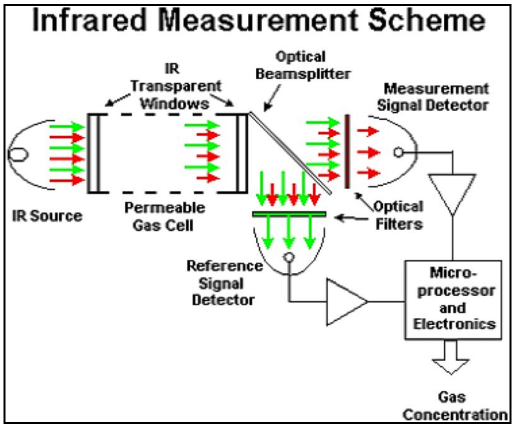
Tubular ceramic: In between the Heater coil and Gas sensing layer, the tubular ceramic exists which is made of Aluminum oxide (Al_2O_3). As it has a high melting point, it helps in maintaining the burn-in (preheating) of the sensing layer which gives the high sensitivity for the sensing layer to get efficient output current.

Mesh over the sensing element: In order to protect the sensing elements and the setup, a metal mesh is used over it, which is also used to avoid/hold the dust particles entering into the mesh and prevent damaging the gas sensing layer from corrosive particles.

Working Principle:

The ability of a Gas sensor to detect gases depends on the chemiresistor to conduct current. The most commonly used chemiresistor is Tin Dioxide (SnO_2) which is an n-type semiconductor that has free electrons (also called as donor). Normally the atmosphere will contain more oxygen than combustible gases. The oxygen particles attract the free electrons present in SnO_2 which pushes them to the surface of the SnO_2. As there are no free electrons available output current will be zero.





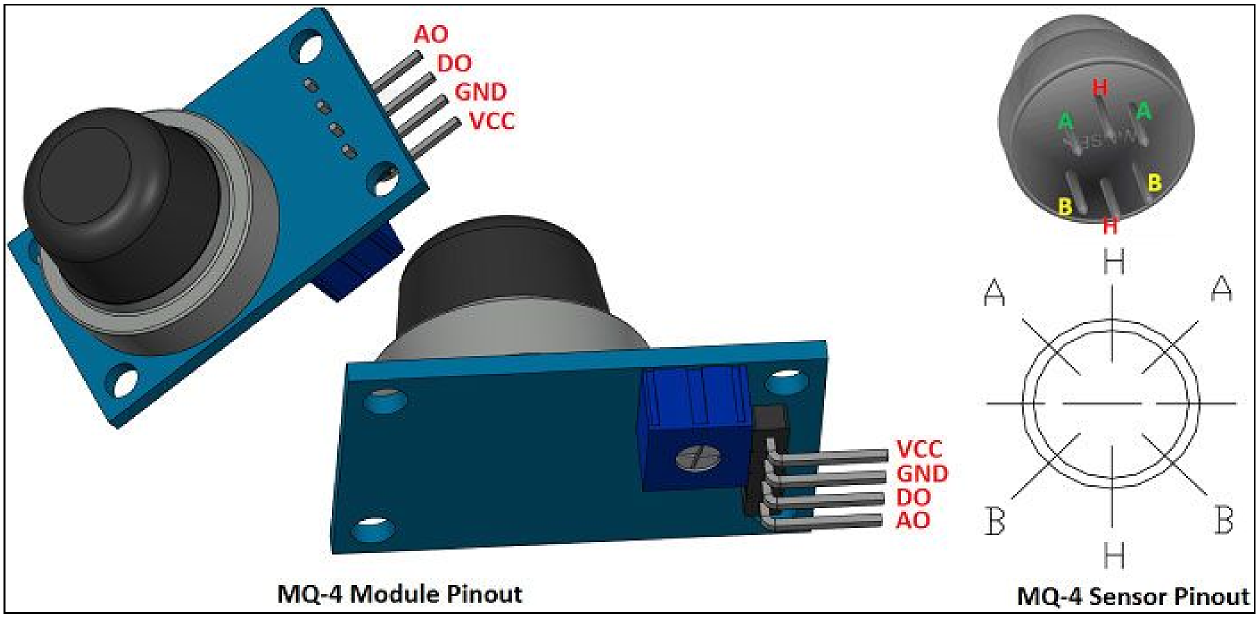
When the sensor is placed in the toxic or combustible gases environment, this reducing gas (orange color) reacts with the adsorbed oxygen particles and breaks the chemical bond between oxygen and free electrons thus releasing the free electrons. As the free electrons are back to their initial position they can now conduct current, this conduction will be proportional to the amount of free electrons available in SnO_2, if the gas is highly toxic more free electrons will be available.

Infrared point sensors measure the absorption and reflection of IR light when interacting with gases. As a type of optical sensor, IR point sensors consist of multiple infrared emitters and photodiodes that determine the concentration and type of gas in a given space. The same principle is used with ultrasonic gas sensors, but instead of IR, ultrasonic sensors use sound waves to determine concentration. Caliometric sensors are specifically designed to interact with explosive gasses such as hydrogen and methane. These sensors react with the explosive gases to create a corresponding amount of heat.

A basic gas sensor has 6 terminals in which 4 terminals (A, A, B, B) act as input or output and the remaining 2 terminals (H, H) are for heating the coil. Of these 4 terminals, 2 terminals from each side can be used as either input or output (these terminals are reversible as shown in the circuit diagram) and vice versa.

These sensors are normally available as modules (shown right), these modules consist of the gas sensor and a comparator IC. The gas sensor module basically consists of 4 terminals:

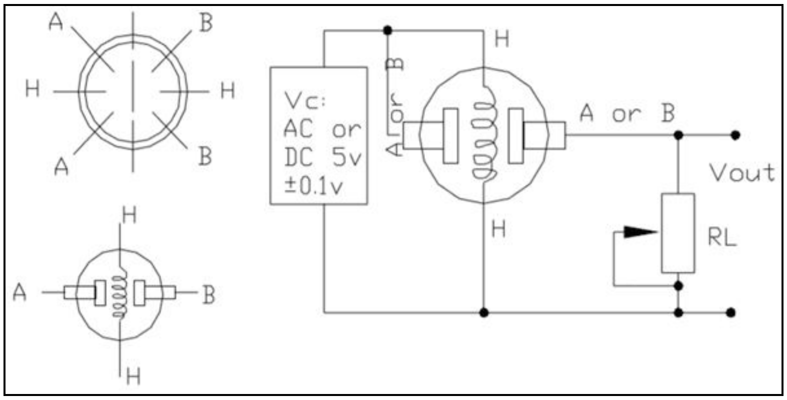
- Vcc – Power supply
- GND – Power supply
- Digital output – This pin gives an output either in logical high or logical low (0 or 1) that means it displays the presence of any toxic or combustible gases near the sensor.
- Analog output – This pin gives an output continuous in voltage which varies based on the concentration of gas that is applied to the gas sensor.



As discussed earlier the output of a gas sensor alone will be very small (in mV) so an external circuit has to be used in order to get a digital high low output from the sensor. For this purpose, a comparator (LM393), adjustable potentiometer, some resistors and capacitors are used.

The purpose of LM393 is to get the output from the sensor, compare it with a reference voltage and display whether the output is logically high or not. Whereas the purpose of the potentiometer is to set the required threshold value of the gas above which the digital output pin should go high.

The below diagram shows the basic circuit diagram of a gas sensor in a gas sensor module.



Here A and B are the input and output terminals (these are reversible - means any of the paired terminals can be used as input or output) and H is the Heater coil terminal. The purpose of the variable resistor is to adjust the output voltage and to maintain high sensitivity.

If no input voltage is applied to the heater coil, then the output current will be very less (which is negligible or approximately 0). When sufficient voltage is applied to the input terminal and heater coil, the sensing layer wakes up and is ready to sense any combustible gases nearby it. Initially let's assume that there is no toxic gas near the sensor, so the resistance of the layer doesn't change and the output current and voltage are also unchanged and are negligible (approximately 0).

Now let's assume that there is some toxic gas nearby. As the heater coil is preheated it is now easy to detect any combustible gases. When the sensing layer interacts with the gases, the resistance of the material varies and the current flowing through the circuit also varies. This change in variation can be then observed at the load resistance (RL).

The value of load resistance (RL) can be anywhere from 10KΩ to 47KΩ. The exact value of the load resistance can be selected by calibrating with the known concentration of the gas. If low load resistance is selected then the circuit has less sensitivity and if high load resistance is selected then the circuit has high sensitivity.

Competitors:

1. DFRobot released its latest high-precision analog infrared arduino CO_2 sensor. The effective measuring range is from 0 to 5000ppm. This sensor is based on non-dispersive infrared (NDIR) technology and has good selectivity and oxygen-free dependency. Besides, its service life could be up to 5 years! It integrates temperature compensation and supports DAC output. Most importantly, the product is easy to use; it is compatible with all types of microcontrollers such as Arduino with ADC function. In addition, Analog Infrared CO_2 Sensor For Arduino (0~5000 ppm) is a high-performance sensor that combines technology of mature infrared absorption gas detection with precision optical circuit design as well as

sophisticated circuit design. It has characteristics such as high sensitivity, high resolution, low power consumption, fast response, anti-water vapor interference, no poisoning, high stability and long life. Analog Infrared CO_2 Sensor is able to directly compatible with the DFRobot Arduino IO expansion board thanks to its external DFRobot Gravity interface. This character simplifies the use of the sensor as it is plug and play and does not need additional wiring. This CO_2 Sensor could be widely used in HVAC, indoor air quality monitoring, industrial process and security protection monitoring, agriculture and animal husbandry production process monitoring.

2. MH-Z14A NDIR Infrared gas module is a common type, small size sensor, using non-dispersive infrared (NDIR) principle to detect the existence of CO_2 in the air, with good selectivity, non-oxygen dependent and long life. Built-in temperature compensation; and it has digital output, analog
3. Chemtrols- Chemtrols Industries Pvt. Ltd. is a leading solutions' provider of B2B Solutions in the field of Process Analytics, CEMS, AAQMS, Gas Detection, Terminal Automation.Flame and Gas Detection systems with/without SIL certified controlling & PLC conforming IEC 61508.

These systems are also supplied wireless communication using HART/ ISA 100/ GSM wireless.

- SIL 2 certified Hybrid Sensors
- SIL 3 certified Controllers
- Point IR Gas Detectors
- Open Path IR Gas Detectors

- Catalytic Detectors
- Electrochemical Detectors
- Metal Oxide Semiconductor Detectors
- Flame Detectors
- Photo Acoustic Detectors
- Ultrasonic Gas Leak Detectors

4. Subtronics Pvt Limited India

   Simple, compact, light weight, easy to use portable smoke checker. Beeps on detecting smoke with auto reset.

Options available : (general purpose or selective for smoke)

- MP-21 Basic (General purpose for smoke) - standalone without probe
- MP-21 with fixed flexible probe - Detect easily even in hard to reach confined spaces

5. Toshniwal sensing devices private limited - gas sensors and modules

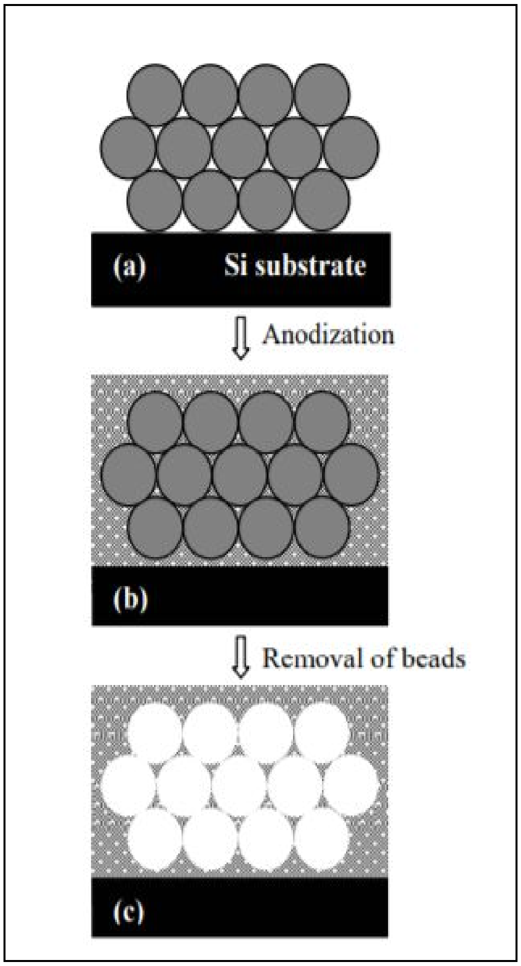
6. Tritech - World Renowned Gas Detection Instrument Manufacturer

7. Gas Sensors by Figaro offers a wide range of gas sensor products for the detection of various gases, from explosive gases such as propane, toxic gases such as carbon monoxide, to air quality sensors for volatile organic compounds (VOCs) that are responsible for sick-house syndrome. Figaro offers a diverse portfolio of sensor technologies that can be matched to the unique requirements of each application.

Types of Arduino based gas Sensors available in the market:

Sensor Name	Gas to Measure
MQ2	Methane, Butane, LPG, Smoke
MQ3	Alcohol, Ethanol, Smoke
MQ4	Methane, CNG Gas
MQ5	Natural Gas, LPG
MQ6	LPG, Butane
MQ7	Carbon Monoxide
MQ8	Hydrogen Gas
MQ9	Carbon Monoxide, Flammable Gas
MQ131	Ozone
MQ135	Air Quality
MQ136	Hydrogen Sulphide Gas
MQ137	Ammonia
MQ138	Benzene, Toluene, Alcohol, Propane, Formaldehyde Gas, Hydrogen
MQ214	Methane, Natural Gas
MQ216	Natural Gas, Coal Gas
MQ303A	Alcohol, Ethanol, Smoke
MQ306A	LPG, Butane
MQ307A	Carbon Monoxide
MQ309A	Carbon Monoxide, Flammable Gas

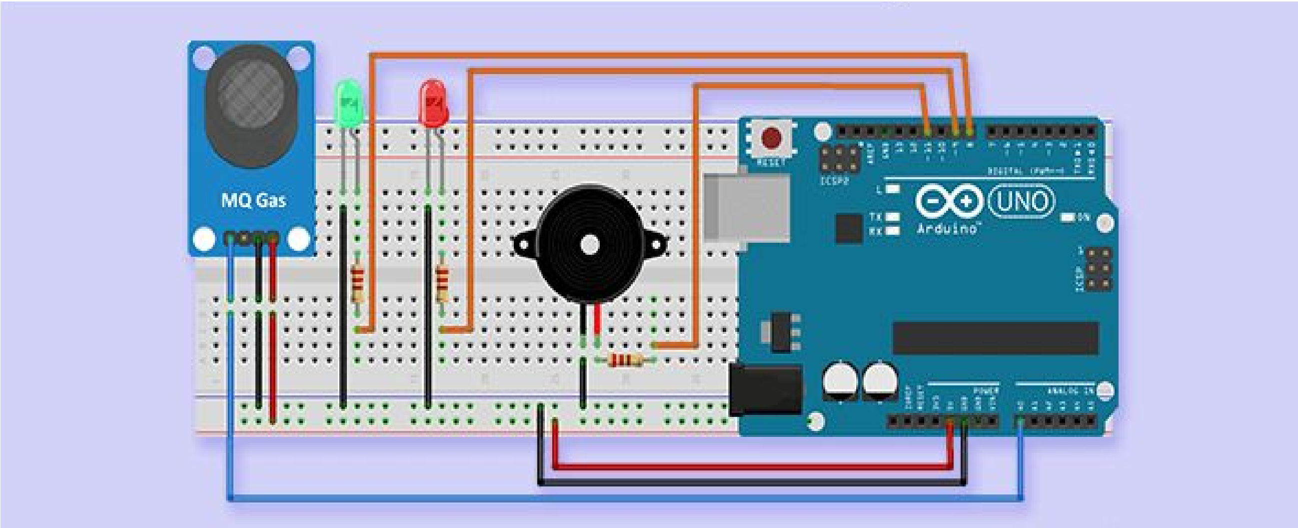
How to manufacture Colloidal Inverse Opal Photonic Crystal?



The manufacturing method approaches the fabrication of 3D porous structures using spherical colloidal particles as templates for the anodization of the underlying substrate in an aqueous solution. In this process, the void can be filled with the silicon oxide produced on a Si substrate by localized anodization. The figure shows the schematic of the templating of the colloidal crystal structure on a Si substrate. The templating process used to fabricate the 3D porous structure was carried out as described previously. A p-type Si wafer (0.005-0.01 cm, (100) crystal orientation) was used as the substrate.The monodisperse suspension of polystyrene beads (PS, 0.2% solids) was dropped onto the substrate. The suspension drop was dried in air, and the nanospheres self-assembled into a closely packed structure with 3D ordered lattices via attractive capillary forces. After the complete evaporation of the solvent, the Si substrate with the colloidal crystal structure of PS beads was anodized at a constant current density of 0.3 mol/dm3 oxalic acid at 20. The formation behavior of silicon oxide on the Si substrate was examined by measuring voltage transient at a constant current density and observing the obtained structure at different stages after dissolving the PS beads in toluene. The ordered geometric structure formed on the Si substrate was evaluated by field emission scanning electron microscopy.

Bill of Materials for Proposed Sensor:

1. Radiation source
2. Detector
3. Inverse opal structure made of cross-linked silicon dioxide colloidal crystal
4. Requirements to fabricate a crystal
    a. P type Si wafer as substrate
    b. Polystyrene beads (0.2% solids)
    c. Electric Voltage 20V
    d. 0.3 mol/dm3 oxalic acid
    e. Scanning Electron Microscope
    f. Vessel
5. A Pcb
6. Capacitors and Resistors (50 k-Ohm)
7. An Arduino



Challenges in Manufacturing:

Higher-dimensional photonic crystal fabrication faces two major challenges:

- Making them with enough precision to prevent scattering losses blurring the crystal properties
- Designing processes that can robustly mass-produce the crystals
- Major effort is to develop self-assembly approaches to meet the requirements for manufacturing. Fabrication of large scale and high quality photonic structures are required in the transition from laboratory to industrial practice, including further improve their resolution and discrimination.
- Secondly, most of the biosensors produce single-shot measurements only and are not able to monitor a species continuously, which is typically required for many types of clinical diagnosis. For example, the detection of glucose is single-use activity, dynamic monitoring is not achieved.
- Thirdly, the selectivity of PC sensors also needs to be improved. The PC-based sensors, such as creatinine, are often affected by the ionic strength of a solution or by other analytes. When designing new systems with improved performance, we should learn from the natural photonic structures, which appears to have excellent properties and provides replicated bio-templates for the design of novel photonic materials.

Considering the above challenges the following decisions has been made for a batch of sensors:

Index	Product	Cost to manufacture/ procure	Decision to procure from Vendor (V) / Self Manufacture(M)
1.	Radiation Source	Rs 43,190	V
2.	Detector	Rs 10, 200	V
3.	P type Si wafer	Rs 950	V
4.	Polystyrene Beads	Rs 500/kg * 5kg	V
5.	Electric Voltage Step Down Transformer	Rs 425	V
6.	Oxalic Acid	Rs 24/kg * 5 kg	V
7.	Scanning Electron Microscope	Rs 18000 (per unit)(alibaba.com)	V
8.	Printed Circuit Board	Rs 750	M
9.	Capacitors	Rs 475/unit *4	V
10.	Resistors	Rs 4.5/unit *5	V
11.	Arduino	Rs 330	V
12.	Sio2 Colloidal Crystals	Total Cost: Rs19900	M
	Total Cost of Sensors for 1 batch of 15	**Rs 25000**	

Selling Cost per Sensor to the Market: Rs 8000

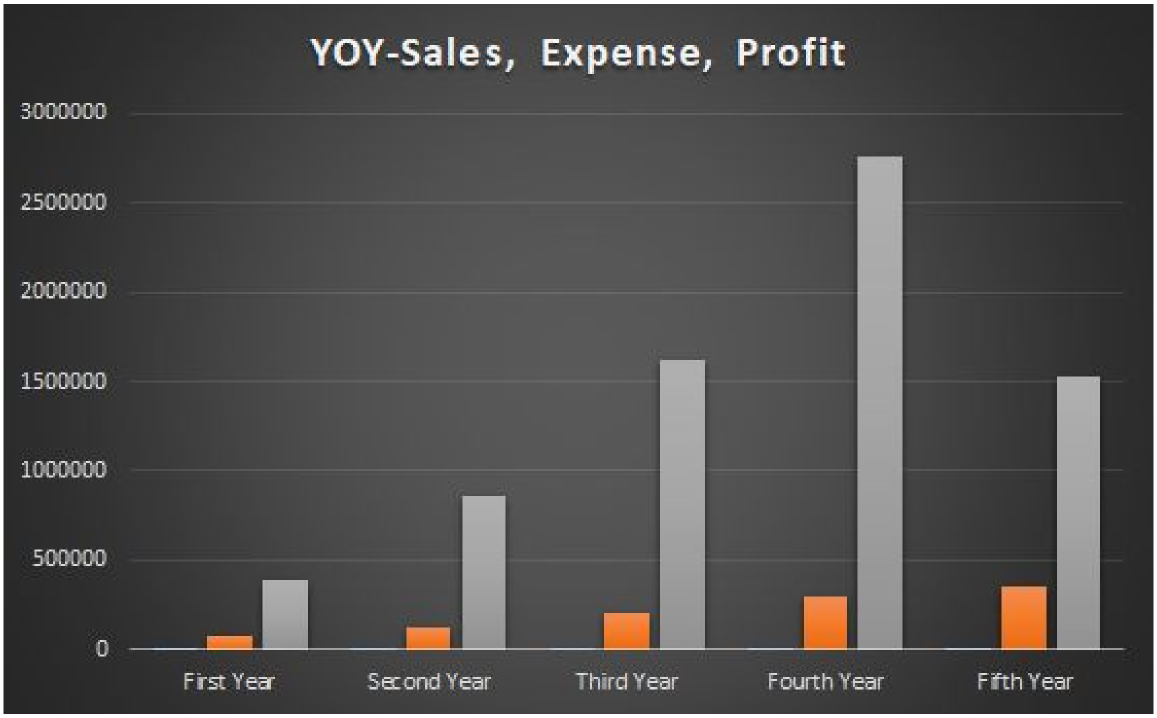
Capital Expenditure for 4 years: Rs 24 lakhs

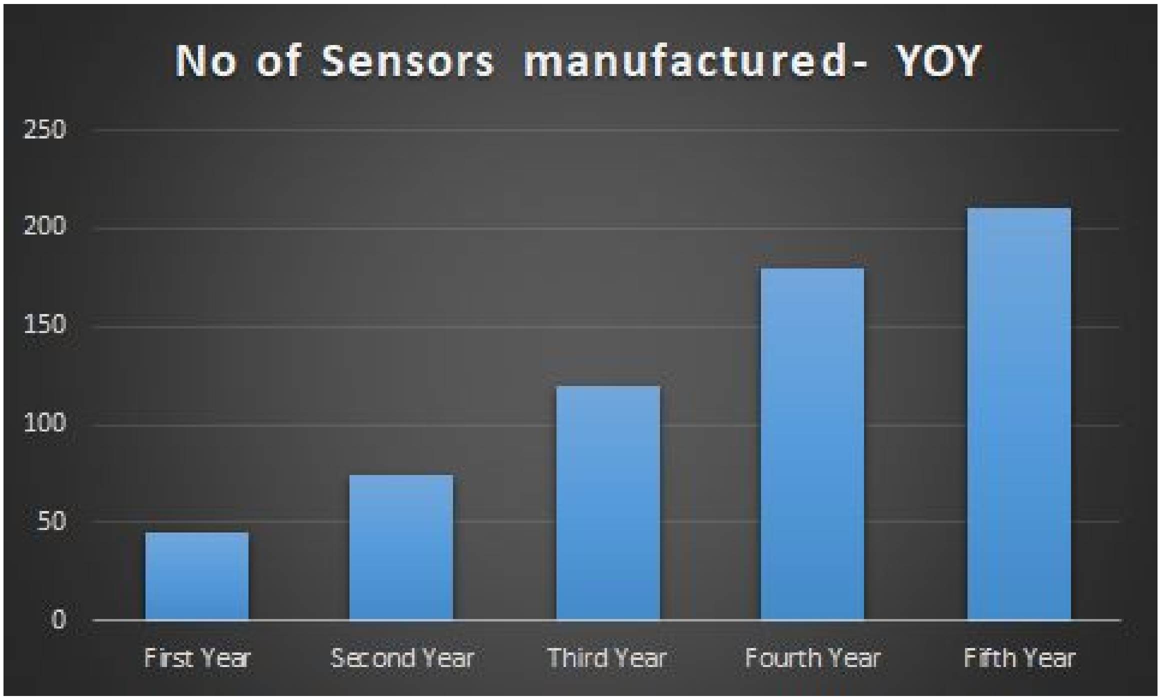
Spreadsheet link :Business Analysis for Optical Gas sensor using Photonic Crystals

				1 lakh in hand will be used for inital expenditure of 75000			
	No of Sensors	Selling cost of 1 sensor	Total Selling Cost	Total Expenditure	Profit	Balance at Beginning of the Year	
First Year	45	8000	360000	75000	385000	25000	
Second Year	75	8000	600000	125000	860,000	260000	
Third Year	120	8000	960000	200000	1620000	660000	
Fourth Year	180	8000	1440000	300000	2760000	1320000	
Loan of 25 lakhs Repayed						200000	
Fifth Year	210	8000	1680000	350000	1530000	200000	Loan of 5 lakhs will be taken
Sixth Year						1830000	

5 year Growth Plan:

Having 1 lakh in hand after investing on capital, we plan on using 75000 Rs for manufacturing 45 sensors in the 1st year. The above table predicts the growth of our Company and we will **Break Even** and repay the loan of 24 lakhs within 4 years. An additional 5 lakhs will be taken as loan at the end of 4th year for efficient functioning and to keep the accounts in check and running. The number of sensors produced per year increases substantially as our yearly revenue increases. The entire prediction has been done taking into consideration that labour costs and selling price are kept at constnat rates throughout the period of 5 years.


YOY-Sales, Expense, Profit
3000000
2500000
2000000
1500000
1000000
500000
0
First Year
Second Year
Third Year
Fourth Year
Fifth Year


No of Sensors manufactured- YOY
250
200
150
100
50
0
First Year
Second Year
Third Year
Fourth Year
Fifth Year

Captial Investment of Lease
18000
43,190
10200
71390
Warehouse Cost
35000
Worker Cost
20000
Research Cost
32000
Misc - Repair/ Service/ Overhead/Calibration
10000
Marketing Cost
15000
Logistics Cost
8000
Internal Operations - Electricity
8000
Total Cost per month
199390
Expenditure for 4 years
2392680

Reason for procuring:

The cost of machines to manufacture the components is very high and the costs to operate the machines increase the effective cost of the components. This cost of components is higher than the cost quoted by the distributors like amazon, ebay and other vendors.

Some machines like Scanning Electron Microscope, which cost around 130Lakhs, are leased for 18000Rs per year.

The laser source and detector is taken on lease due to the same reason listed above.

The PCB manufacturers are available in the market.(The required pcb layout is to be given and the customized PCB is manufactured and delivered to the location of the plant).

Using Porter's 5 forces model, the bargaining power of suppliers is low and bargaining power of consumers is moderate due to the presence of the existing gas sensor market. The threat of substitutes is very high due to the stable current gas sensors manufacturing system and the threat of new entrants is low due to high capital investment and the cost of machines is very high as mentioned above.

In- House Manufacturing:

The components required to manufacture the inverse opal SiO2 structure are:

1. P type Si wafer
2. Polystyrene Beads
3. Electric Voltage Step Down Transformer
4. Oxalic Acid
5. Scanning Electron Microscope
6. Vessel

Testing and Calibration of Sensor:

1. The sensor's efficiency and its ability to be used for various applications is based on the 3D porous structure of the inverse opal. It is important the porosity is around 74%, for the refractive index to increase which increases the sensitivity of the sensor, hence scanning electron microscopy is used for determining this complex simple to manufacture structure.
2. This structure of the inverse opal has to be verified before it can be used for the manufacturing of the sensor. Due to the various possible applications for the sensor, the inverse opal structure is cross verified with known images and dimensions using experimental and theoretical verification.
3. It has to be confirmed that the networks of silicon oxide, that is, the hollow spaces of air spheres isordered in a triangular lattice, the interval of which was in good agreement with the diameter (474 nm) of the PS beads used as a template. The three dark spots inside each hole indicate the air spheres of the underlying layer, which were formed at spots of contact between beads. That is, the voids between the particles were filled with the silicon oxide produced on the Si substrate by anodization.
4. If the anodized inverse opal structure fails the above calibration and testing, it is important to re-anodize this internal self assembled structure for repurposing.
5. Once this structure has met the minimum regulations, the sensor can be fabricated as mentioned above.
6. This fabricated sensor now has to be tested for its photonic band gap by providing a light of wavelength, output should be a known colour associated with the given wavelength of light. This step is important since there is no current method for standardization of the sensor since

the inverse opal structure varies due to environment and pressure conditions.

7. To counter this problem, we propose that the photonic band gaps of this structure can be varied by providing appropriate electric impulses and allowing the structure to restructure accordingly.
8. Indian Sensor Testing Regulatory Body has to validate the sensor.

Summary of Testing/ Calibration:

Due to recent extensive research in this domain, the above proposed testing methods are only theoretical. However without practical research it would not be possible to to verify the above stated procedure.

A rough estimation of the cost of this process is mainly based on the Scanning Electron Microscope which would be around Rs 18,000 and the cost of light source used for calibration would be around Rs 75000. However the microscope and source are also used for the manufacturing process and hence can be accordingly reduced from the total initial investment.

Manufacturing Layout:

Booth 1: Procuring and Storage of Materials

Booth 2: Making the Inverse Opal SiO_2 Crystals

Booth 3: Making PCB Circuit

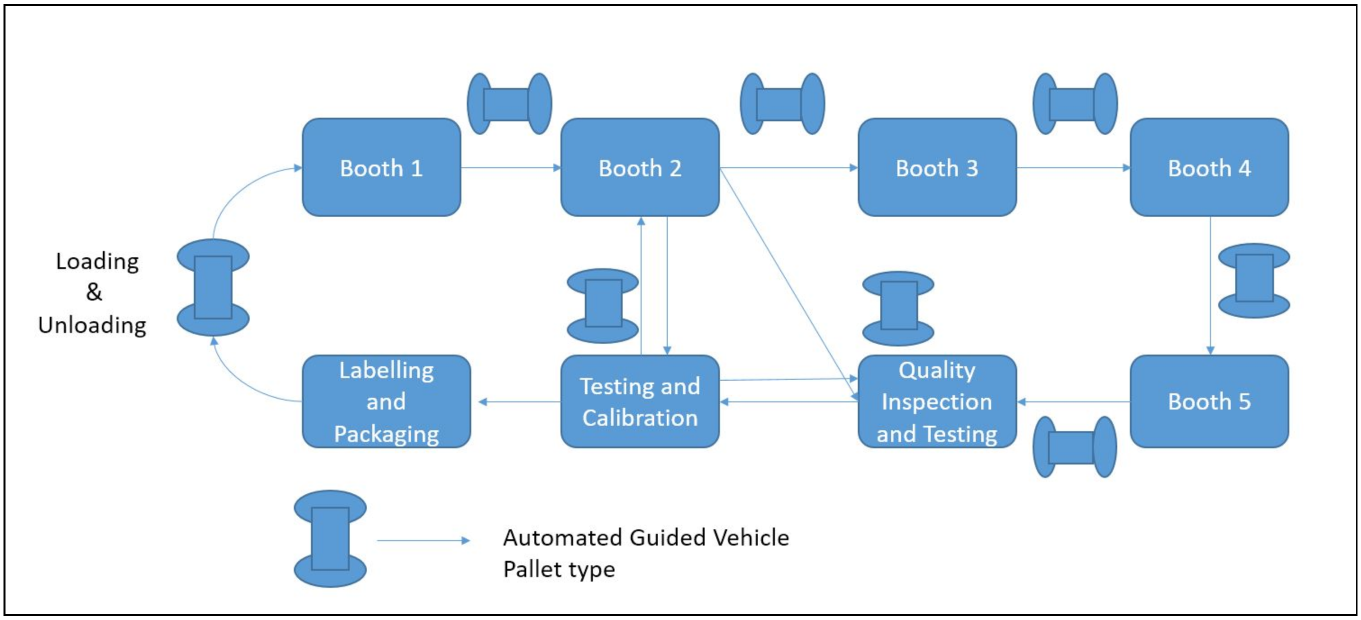
Booth 4 **:** Integrating Electronic Circuit with Photonic Crystals

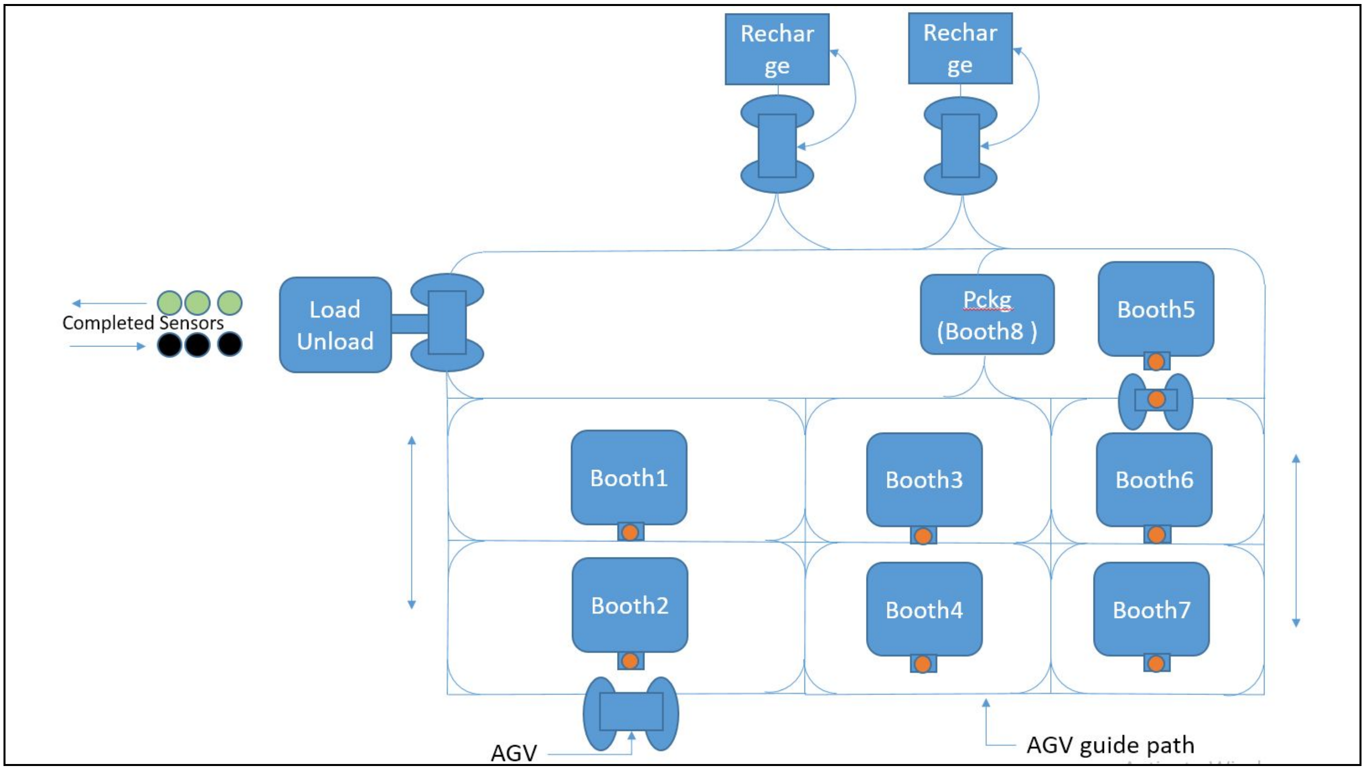
Booth 5: Assembling

Booth 6: Quality Inspection

Booth 7: Testing and Calibration

Booth 8: Packaging


Booth 1
Booth 2
Booth 3
Booth 4
Loading
&
Unloading
Labelling and Packaging
Testing and Calibration
Quality Inspection and Testing
Booth 5
Automated Guided Vehicle
Pallet type


Rechar ge
Rechar ge
Completed Sensors
Load Unload
Pckg (Booth8)
Booth5
Booth1
Booth3
Booth6
Booth2
Booth4
Booth7
AGV
AGV guide path

We are using a **Multi Cell Dedicated Flexible** manufacturing system as the variety and number of different sensors manufactured is limited and number of products manufactured is also pre defined and does not fluctuate. The type of **AGV** used is the **Pallet type** as the load carried is less than 35kgs.

The process starts from loading the materials in booth 1.Then, with given materials inverse opal using SiO_2.Then the Quality is inspected in booth 6. After the quality is inspected, it goes to the PCB booth where the PCB layout is made and the board is custom fabricated. After the board is fabricated, the crystals are electrically coupled with arduino and the whole set up is assembled. After this the quality is inspected , and it goes to the testing section. In the testing section, the photonic Band Gap of the crystals are experimentally found. And with known gas-light characteristics , the sensor is calibrated.

After this, the sensor is labelled and packed and sent for OUTBOUND Logistics.

Future Applications of Photonic Crystals:

1. PhCs provide good platforms for drug loading and biomolecule modification, which could be applied to biosensors, biological carriers and tumor screening.
2. A large number of PC based sensors have been theoretically developed that have been designed to respond to external stimuli such as mechanical stress, temperature, electric fields, magnetic fields and chemicals.
3. PhCs can be used not only to tune the delivery of a drug but also to act as self-monitoring sensors, both of which have great potential in drug delivery systems.
4. The PC materials for this detector are composed of polystyrene crystalline colloidal arrays and polyacrylamide hydrogels. To realize quantitative detection, a pH-responsive polymerized crystalline colloidal array (PCCA) was combined with an enzyme reaction that liberates OH^-. In this series of

reactions, creatinine is first hydrolyzed by creatinine deaminase, which leads to the release of hydroxide ions. Then 2-nitrophenol in the hydrogel titrates the resulting change in pH, which causes the PCCA hydrogel to swell. The creatinine concentration is then visualized and quantified by measuring the diffraction red shift.

5. PCs can also be responsive to glucose, which offers a new method for diagnosing diabetes.

Future Applications of Inverse Opal Photonic Crystal Gas Sensors:

- Used in industries to monitor the concentration of the toxic gases.
- Used in households to detect an emergency incident.
- Used at oil rig locations to monitor the concentration of the gases that are released.
- Used at hotels to avoid customers from smoking.
- Used in air quality check at offices.
- Used in air conditioners to monitor the CO_2 levels.
- Used in detecting fire.
- Used to check concentration of gases in mines.
- Breath analyzer.

References:

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