Introduces yourself

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- Now what is neuromorphic computing?
- A simple answer will be, mimicking your brains computation process
- But Why is that required?
- Indeed, computers have grown far faster than brain in any sort of computation
- But there are certain distinct capability of brain like face recognition in a crowd by looking at 3 quarter of the face, this sort of higher cognitive skills is where our brain excels, and it consumes very low energy to perform
- In time, a lots of AI algorithms are developed and its keep on developing
- But all this algorithm runs on transistor based devices, like computers and servers
- Which are power hungry
- Here is an example, of Nvidia’s NLP model, MegatronLM, which consumed about 27, 684 kWh on training for 9 days
- Here in this figure I have shown a schematic presentation of an artificial neuron and my proposed device, which I will talk about in the future slides
- One of the key feature of my proposed device is that it will perform non-boolean computation unlike a transistor

- Here is quick recap of Artificial Neural Network
- ANN is a system of interconnected neurons
- The way this neurons are connected to each other, is output of a neuron is connected to all other neurons in the next layer
- Mainly there are three layers in NN, Input layer, where the user will feed in the data, Output layer, where the user will recive the output data from the NN, and the hidden layer, where the internal computation of the NN happens
- A neuron constitutes of, inputs, weights and biases, summation block and the activation bloak

- The neuron computes through two sequential process, summation and activation
- In summation block, whatever the input is received by the summation block, it just adds them up, and provides the output to the activation block
- Activation block is a non-linear mathematical function, which is inspired from the biological neuron, that is in biological neuron, whenever a neuron gets inputs from many different other neuron, it at first adds them up, if the resultant signal is not up to a certain threshold value, the neuron does not transmit the data, else it will transmit, this behaviour is captured by the activation function
- In a NN, the weights and the biases are the optimizing parameters
- A neuron transmit signals to another neuron, through the edges connected within them, this edges have a weight term associated with them, that is the strength of the edge
- Each neuron posses a bias term, which serves as the threshold for the activation block

- Neural network is a two phase process: Training phase and Evaluation phase
- In training phase, the model is trained training data, training data are those data for which the output is known for a given input
- In this phase, the input X is feed into the model, it gives the output O, which is sent to a error function, where the error is calculated, ans based on this error, the weights are constructed and optimized, the training phase continues until and unless we get minimum error
- Then we have the evaluation phase, after the model is fully trained, we feed in data, and get output, evaluation phase is only done, when the model is fully trained, iz. The chance of getting error is low

- Here is an implementation of a character recognition model, which I presented in the mid term
- Where we provide a noisy pixel value of a 7x5 character into the fully trained model, and the model predicts the original character with minimum error

- Now I will present on spintronics
- We know an electron apart from having a charge also posses a spin
- We can use the spins as binary bits, that is UP spin as 1 and DOWN spin as 0, or vice versa
- The spintronic devices have some inherent advantages over transistor, that they are non-volatile in nature and are endurable, where as a transistor is volatile in nature, and it requires some extra circuitry to have non-volatile nature
- In changing bits, we just required to rotate the spin, since it is just spin rotation and there is no charge movement, hence there is no ohmic dissipation
- But there is dissipation due to magnetization damping
- But to rotate the spins, we need to apply external charge voltage/current, and there is dissipation due to that
- It is seen that, at 100 nm dimension, all the spins are in one direction, which we can represent as one big spin, and experimentally it can be done through EBL

- Now I will talk about magnetic anisotropy, which means magnetization is not same in all the direction, and hence the energy
- In case of a sphere, there is no anisotropy, as it is symmetric in all direction
- But in case of an ellipsoid, we have anisotropy but it is difficult to fabricate on a planar wafer
- Hence we use a elliptical cylinder, which has in-plane shape anisotropy
- Because of in-plane anisotropy we have phi=+-90, we have different energy at different values of theta, and the energy is given by the equation
- Here we can see, the Energy is minimum, when theta = 0 or 180, that is at this values of theta, we can store our UP or DOWN spins, also at theta theta = 90, we have a energy barrier, which prevents the spontaneous fluctuation of spin from UP to DOWN and vice versa
- Here the Hk is the coercive field, that at this filed, even after application of magnetic field, the magnetization is zero
- Generally, the Energy barrier, is not kept very high, because it will create difficulty while changing the spins, it is generally kept in between 30 to 80 KT, and it is seen that at 40 KT the data retention time in 10 years

- In this slide it demonstrate, the effect on spin rotation on application of magnetic field along in-plane hard axis
- We have applied the magnetic field in the Y-axis
- Below I have plot of Energy vs theta, where the energy is given by this equation
- And the spin will attain equilibrium, at those theta where the energy is minimum
- So by computing dE/dtheta=0, we get theta_min=sin-1(Hy/Hk)
- When Hy/Hk =0, we have this curve, where theta_min= 0 or 180, that is the spin will subtend 0 degree to the Z axis or 180 with the z axis, the UP spin or DOWN spin can't spontaneously flip, because there is potential hill ahead
- Now when Hy/Hk=1, theta_min is shifted to 45 or 135 degree, that is the UP spin will subtend 45 degree to the Z axis or DOWN spin subtends 135 with the z axis
- If we make Hy/Hk=1.4, theta_min becomes 90, that is the UP spin subtends 90 degree to the Z axis or DOWN spin also subtends 90 with the z axis
- On further increasing the Hy/Hk value, the energy will decrease further but theta_min will always be 90
- Hence we conclude that, we can't rotate the spin by applying magnetic field along in-plane hard axis

- Now if we apply, magnetic field along in-plane easy axis, that is along z axis
- theta_min will be given by sin-1(Hz/Hk)
- Here I have plotted energy vs theta
- When Hz/Hk=0, theta_min = 0 or 180 degree, that is the UP spin subtends 0 degree with z axis, and DOWN spin subtends 180 degree with the z axis
- Similarly if we keep on increasing the Hz/Hk value, we see that there is a potential down hill, towards theta = 180 degree
- So a Hz/Hk becomes 1.4 theta_min=180 degree
- Which means we have fliped our spin,
- Now on slowly removing the externally applied magnetic filed, we see there is a potential up hill from theta = 180 to theta = 0, hence the even after removing the magnetic field, the DOWN spin will not convert back to UP spin
- So form this we conclude that, we can rotate the spin on application of magnetic field along in plane easy axis

- In this slide I will explain the perpendicular anisotropy, that is here the magnetization is perpendicular to planar surface, here the easy axis will be the z axis, ie when theta = 0, 180 degree, and hard axis will be when theta = 90 degree
- The magnet’s plane is phi = +- 90 degree
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- In this slide we will talk about Multiferroics and multiferroic composites
- In nature there exist, ferroelectric and ferromagnetic materials, there also exist multiferroic, which exhibit both the properties of FE and FM, that is change in Electric field, will change the magnetization and change in magnetic field will change the polarization
- In the figure below, the E, H, and the stress are the physical parameters which we can change , and the P, M, and strain are the macroscopic observables
- We see that there is intrinsic coupling between E and H, that is change in E will change H, change in H will be reflected on M, similarly the other way around
- The magnetoelectric coupling is given by alphe_ME=.....
- But there are certain issues with multiferroics, that is not siutable for room temperature operation, and the magnetoelectric coupling is weak
- So we use a multiferroic composite, its the composition of Piezoelectric and magnetostrictive material
- This materials are stress mediated, change in E will change the stress due to peizoelectricity, and change in stress , will change the H, and that in turn will canhe the M
- The magnetoelectric coupling is given by alpha_ME

- In the previous slide, we talked about multiferroic composites, where magnetostrictive material played an important role
- So magnetostrictive materials are FM specimens, which changes its shape iz strain during the process of magnetization
- The magnetic anisotropy creates to stress anisotropy, and vice versa
- The stress anisotropy generated is given by the equation 3/2lambda...
- Where lambda is the magnetostriction coefficient, which is the saturation strain generated on application of magnetic field
- The 3/2 lambda values of Cobalt is -30 x 10-6 and Iron-Gallium is 150 x 10-6, this values will be required in the next slide

- Here we have the multiferroic composite, and we apply electric potential to the piezoelectric, which will create strain in the piezoelectric
- The strain is given by the formula epsilon_piezo.....
- The strain will be elastically transferred to the magnetostrictive material
- From that we calculate the stress anisotropy
- And for FeGa the stress anisotropy is 2.4 x 10-18 J

- This is my proposed device, here I will explain, how my device will simulate the artificial neuron
- We have the piezoelectric material, to which we give electric potential as input
- This will stress the piezoelectric
- On the piezoelectric layer we have cylinder like structures, which contains the magnetostrictive layer and TMR
- The stress in piezo will be transfered to the magnetostrictive layer
- The stress anisotropy in magnetostrictive layer will create, magnetic anisotropy
- Which will change the magnetization direction of the lower plate of the TMR
- This will generate variable resistance, which can be used as output of the neuron

- Now I will explain on Magnetic Thermal Annealing
- The lattice and shape deformities in materials can significantly degrade its quality
- Removing the anomalies is necessary to achieve a high quality material and performance
- A common technique is thermal annealing, which is done by raising, maintaing and slowly reducing the temperature of the material
- This allows, atoms inside of the material to diffuse more easily to find their proper location, and maintaining the material at high temperature, lets is achieve equilibrium, eliminating structural imperfection
- Another new technique is MTA
- The difference is ext. Magnetic field is applied during the annealing process

- The most important effect of MTA, in FM material is that it re-orients the easy axis or the axis of the spontaneous magnetization vector
- If a lattice shows specific symmetry, the easy axis will normally reflect the symmetry
- Now if a lattice has more deformities, then there won't be any major global symmetry, which will weekend the magnetization vector
- If a deformed FM, annealed at higher temperature, all the spins of each individual atom will align with the ext. Applied field
- And the temperautre is reduced, the lattice becomes locked or frozen, and the magnet attains a new magnetization direction

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