**Mid Semester**

**Pg. 1: INTRO**

**Pg. 2: Content**

1. **This is my content slide for the presentation**

**Pg. 3: Content**

1. **Where I will briefly recap about the motivational slide, artificial neural network, my implementation of a character recognition model, then on spintronics, magnetic anisotropy, perpendicular anisotropy, Gaint Magnetoresistance and Tunneling magneto resistance**

**Pg.4: Energy-Efficient Neuromorphic Computing**

1. **Traditionally, the neuromorphic computation is usually performed on transistors-based devices, but in my project,**
2. **I'll be using spintronic devices, as it can be more energy efficient and it encapsulates the weight, sum, and activation function, which are the computing elements of the artificial neurons.**
3. **Apart from that it will be performing non-Boolean computation**

**Pg. 5: ANN**

1. **Artificial neurons are inspired from biological neuron**
2. **[CLICK]**
3. **ANN is a system of interconnected neurons, each neurons are connected to each other by edges which has a weight associated with it**
4. **Weights and biases are the optimizing parameters of ANN**

**Pg. 6: ANN: Neural Architecture**

1. **Here is an implementation of a character recognition model in MATLAB, where the I/P is a 35-bit word of a corrupted character and output is a 26-bit word suggesting the original character**

**Pg. 7: Spintronics: Spin-Electronics**

1. **We know, an electron, apart from having a charge, also possess a spin which can be used for binary representation**
2. **Spintronic devices are advantageous over transistor, as they are non-volatile and endurable in nature**
3. **Apart from these, since there is only spin rotation, hence there is no ohmic dissipation, but there is dissipation due to magnetization damping and dissipation due to applied external charge voltage /current**

4. **At dimension less than 100 nm, we find domains where spins are aligned in one direction, which can be represented as one large spin**

**Pg. 8: Magnetic Anisotropy**

1. **Magnetic anisotropy means magnetization is not same in all direction**
2. **In case of a sphere, there is no anisotropy, in an ellipsoid, there is anisotropy, but it is difficult to fabricate on a planar wafer**
3. **[CLICK]**
4. **So, we use an elliptical cylinder, where we have in-plane shape anisotropy**
5. **[CLICK]**
6. **At $\theta = 0\ and\ 180^0$ the energy is minimum which can be used to save spins $at, \theta = 90^0$, we have an energy barrier which prevents the spins from spontaneous fluctuation**
7. **The energy barrier at 40Kt have data retention time of 10 years**

**Pg. 9: Magneto-elastic anisotropy**

1. **There are certain ferromagnetic specimens known magnetostrictive materials whose shape changes during the process of magnetization**
2. **Magnetic anisotropy creates stress anisotropy and vice versa**
3. **The stress anisotropy is given by $\frac{3}{2}\lambda\sigma\Omega\cos^2\theta$, where $\lambda$ is the magnetostriction co-efficient**
4. **For Cobalt: $\frac{3}{2}\lambda = -30 \times 10^{-6}$, and for FeGa: $\frac{3}{2}\lambda = 150 \times 10^{-6}$**

**Pg. 10: Perpendicular Anisotropy**

1. **Perpendicular anisotropy means the magnetization is in the perpendicular direction**
2. **There are 2 types of perpendicular anisotropy: Bulk and interface anisotropy**
3. **[CLICK]**
4. **The energy of the shape can be written as this**
5. **[CLICK]**
6. **Where $N_d(\theta, \phi)$ is written as this**
7. **[CLICK]**
8. **The above eqn can be written by replacing with $H_d and\ H_k$**
9. **[CLICK]**
10. **[CLICK]**
11. **For circular cross-section: $H_d = 0$, hence energy of the perpendicular anisotropy can be written only in terms of $\theta$.**

**Pg. 11: Perpendicular interface anisotropy**

1. **Here we have the VSM results of CoFeb and MgO interface**
2. **It is seen from the figure, for CoFeB thickness =2 nm, we have hysteresis for in-plane and no hysteresis in out-of plane , but when CoFeB thickness = 1.3nm, we have hysteresis in out of plane**
3. **[CLICK]**
4. **That is on decreasing the thickness of CoFeB the interfacial anisotropy dominates the bulk anisotropy**

**Pg. 12: Giant Magneto-Resistance**

1. **In 2007, the nobel prize in physics, was awarded jointly to Albert Fert and Peter Grunberg, for the discovery of Giant Magnetoresistance**
2. **[CLICK]**
3. **Where there is a structure of 3 layer, iron-chromium-iron**
4. **It is seen that when the outer layer magnetization in parallel to each other, there is low resistance and when they are anti-parallel to each other, the resistance is high**
5. **GMR is obtained by these expression at the bottom**

**Pg. 13: Tunneling Magneto Resistance (TMR)**

1. **For TMR, the middle spacer is an insulator like MgO, $Al_2 0_3$**
2. **Here we can see when the outer 2 layer magnetization are both in the UP direction, below the fermi level, the density of states are same for both the layers. Hence electrons can tunnel easily and have less resistance**
3. **But for the case where the outer layer magnetization is in opposite direction, below the fermi level, density of state are not same in both layers. Hence electrons cannot tunnel easily and have higher resistance**

**Pg. 14: Content**

1. **Now I will talk about neural network using spintronics, where I will explain the multiferroic composites and my proposed device**

**Pg. 15: Multiferroic Composites**

1. **In nature there exist multiferroics, which exhibit both the properties of Ferroelectric and Ferromagnetic, but they have a weak magnetoelectric coupling**
2. **[CLICK]**
3. **Hence we use multiferroic composites, which uses piezoelectric and magnetostrictive materials, and it has strongs magnetoelectric coupling and it is stress mediated**

**Pg. 16: Multiferroic composites voltage vs stress anisotropy**

1. **In the multiferroic composites, we choose piezoelectric layer with high de-coefficient and magnetostrictive layer with high magnetostriction**
2. **And we have calculated, for a piezoelectric layer with de-coefficient =3000 pm/V, thickness=100nm and voltage =50mV, we have a stress anisotropy of 2.4 $\times 10^{-18}$ J for FeGa**

**Pg. 17: Proposed device**

1. **In my proposed device, the input will be given to piezoelectric layer in terms of electric potential**
2. **Which will create stress anisotropy in the piezoelectric layer, which will be elastically transferred to Magnetostrictive layer**
3. **This will create the magnetic anisotropy in the magnetostrictive layer, which will inhibit the TMR, to have variable resistance, and in turn will have variable voltage**

**Pg. 18: Content**

1. **Now I will talk about my experimental section, where I will talk about measurement automation with labView, then on Ferromagnetic Resonance, Lock-in amplifier and Schottky diode**

**Pg. 19: Automation in measurement: LabView**

1. **LabView is a Graphical programming environment, where we can control and synchronize different devices, and can also use it as a centralized system for data acquisition**
2. **Here I have shown an example, where I automated a power supply [CLICK] to create the IV characteristics of a MOS transistor, in just one go.**

**Pg. 20: LabView Automation: Electromagnet**

1. **In this labView program I programmed, to control the electromagnet. We can program the current flowing into the coil, measure the magnetic field through a gauss probe connected to the controller**
2. **Here the electromagnet is connected to the controller and the controller is connected to the laptop with labView**
3. **[CLICK]**
4. **In the program, the initialization block starts the electromagnet and creates a session for communication with labView program**
5. **[CLICK]**

6. **Then this block will take the current as input, and it will direct the controller to set the specified current in the coils of the electromagnet**
7. **[CLICK]**
8. **This block directs the controller to measures the magnetic field using the gauss probe connected to it**
9. **[CLICK]**
10. **Finally, the closing block, terminates the session created and stops the electromagnet**

**Pg. 21: LabView Automation: RF signal generator**

1. **This labview program, programs the Signal generator, for output of RF signal at specified frequency and power level**
2. **[CLICK]**
3. **This block, starts a session with RF signal generator for communication**
4. **[CLICK]**
5. **This block, will take the frequency as input and configures the device to generate a RF signal with the specified frequency**
6. **[CLICK]**
7. **Similar to the previous block, this block configures the power level of the RF signal**
8. **[CLICK]**
9. **This block, takes a Boolean input, it configures the device whether to start/stop the signal**
10. **[CLICK]**
11. **This block, terminates the session**

**Pg. 22: LabView Automation: Spectrum Analyzer**

1. **This labView program, retrives the spectrum trace from the spectrum analyzer, and able to put marker on the trace**
2. **[CLICK]**
3. **This block, starts a session with Spectrum Analyzer for communication**
4. **[CLICK]**
5. **This block configures the spectrum analyzer for number of sweeps and sweep mode**
6. **[CLICK]**
7. **This block fetches the trace displayed in the spectrum analyzer**
8. **[CLICK]**
9. **This marker block searches a position on trace to put a marker on it**
10. **[CLICK]**
11. **This block, retrives the data from the marker, like marker position and marker amplitude**

12. **[CLICK]**
13. **This block, finally terminates the session with the device**

**Pg. 23: Ferromagnetic Resonance**

1. **When a magnetic field is applied to a magnetic material, the magnetization precessies and it follows a Archimedean spiral motion**
2. **[CLICK]**
3. **This is given by the Landou Libshitz eqn, where $\gamma$ is the gyromagnetic ratio and $\alpha$ is the damping parameter**
4. **Our aim is to find the damping parameter, through the ferromagnetic resonance experiment**
5. **[CLICK]**
6. **To negate the damping, so that the magnetization keeps on rotating, we apply a transverse AC field**
7. **[CLICK]**
8. **For In-palne FMR, $\omega$ is given by this [CLICK] and for perpendicular FMR $\omega$ is given by this**
9. **[CLICK]**

**Pg. 24: Ferromagnetic Resonance**

1. **The FMR absorption is given by the imaginary part, known as the Lorentzian**
2. **Whose plot against DC field is plotted aside**
3. **We see at $\omega = \omega_0$, we get a resonance**
4. **[CLICK]**
5. **If we differentiate Lorentzian wrt Hdc, we get the derivative FMR spectra**

**Pg. 25: Ferromagnetic Resonance**

1. **Where the width between the maxima and minima of the derivative FMR is $2\Delta H$, where the $\Delta H$ is the FMR linewidth**
2. **And from the $\Delta H$, $\alpha$ can be calculated using the expression in green box**

**Pg.26 Ferromagnetic Resonance: Experimental Setup**

1. **This is the experimental setup I have designed in our lab for ferromagnetic resonance**

2. **Here we put the sample in the co-planar waveguide, the input of the waveguide is connected to the RF signal generator , and the output of the waveguide is connected to the spectrum analyzer.**
3. **The waveguide along with sample is placed in between the electromagnet**
4. **Here the electromagnet provides the DC field, the transverse AC field is provided by the RF signal generator**
5. **And the FMR signal is measured at the spectrum analyzer**
6. **The whole setup is controlled, and data acquisition is done by the labView program**

**Pg. 27 Ferromagnetic Resonance: Experimental Setup**

1. **This is a schematic representation of the Ferromagnetic resonance experimental setup**

**Pg. 28 Ferromagnetic Resonance: Result**

1. **This is the FMR result, we got from our lab setup for a magnetic hard disk sample**
2. **Here we can see the Lorentzian but it is very noise**
3. **To retrieve the FMR signal we could have use a lockin amplifier, but unfortunately due to some missing cables we were not able to automate it**

**Pg. 29 Lock-in Amplifier**

1. **We saw we required a lockin amplifier for retrieving signal buried in noise**
2. **Let say we have a signal whose amplitude is 10nV and frequency is 10kHz, [CLICK] the good amplifier noise is 5nm/$\sqrt{Hz}$, and the bandwidth is 100kHz**
3. **Generally we think if we amplify the signal the problem is solved**
4. **[CLICK]**
5. **Now if we amplify the signal, lets say the gain is 1000,**
6. **[CLICK]**
7. **Then the signal will be $10\mu V$ and the noise is 1.6mV, noise is higher than signal which is pretty bad**
8. **That is where the Lockin amplifier comes into play.**
9. **[CLICK]**
10. **The PSD in a lock-in amplifier can detect a signal at 10kHz with bandwidth as narrow as 0.01 Hz**
11. **[CLICK]**
12. **Which makes the noise 0.5 $\mu V$**

**Pg. 30: Lock-in Amplifier**

1. **Now I will explain the basics of the Lock-in amplifier**

2. **We have signal, Vs and the reference signal Vr, which is send to multiplier, for the top multiplier the reference signal is sent directly, and for the bottom multiplier the reference signal is 90 degree phase shifted**

**Pg. 31: Lock-in Amplifier**

1. **On multiplying the signal and the reference , we get a signal with two frequency component, one at fs + fr and another at fs-fr**
2. **[CLICK]**
3. **When the fr is set to equal to fs, we get a high frequency component and a dc component at 0Hz**

**Pg. 32: Lock-in Amplifier**

1. **By using a low pass filter, we can remove the high frequency component**
2. **Which gives us the X and Y, X is known as In-phase component and Y is known as the Quadrature component, The X and Y are 90 degree phase shifted**
3. **From X and Y, the R and $\theta$ is calculated**

**Pg. 33: Schottky Diode**

1. **In FMR experiment, the output will be a very high signal**
2. **We are using a Schottky diode, for rectifying signal at higher frequency range, so that when we can at least measure some signal**
3. **In the following figure, we see the rectified signal at 10 MHz**