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Effect of Platinum Thickness on Spin Hall Voltage for Spintronic Devices

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Abstract—*Paramagnetic heavy metal platinum exhibit spin Hall effect that convert applied charge current into transverse spin current and vice versa due to large spin-orbit coupling. Spin of moving charge electron interact with orbital motion of impurity atom which deflect opposite spins in transverse directions thus produces spin Hall voltage. Spin Hall voltage in Pt films has been determined and analyzed with respect to thickness of the films. Thin films of Pt have been deposited by RF magnetron sputtering by varying deposition time. Deposited Pt films thickness has been obtained as 60 nm, 45 nm and 30 nm respectively. With decrease in film thickness, resistance of the films has been observed increasing as 20 Ω, 70 Ω and 1.2 kΩ respectively. On applying fixed charge current density 1.5 mA/cm^3 on Pt films, spin Hall voltage has been measured in transverse direction 1.2 mV, 1.9 mV and 4.2 mV. It reveals with reducing thickness of Pt film drastically enhances the spin-orbit interaction resulting into increased spin Hall voltage. Such films can be used to design and develop a low power microwave nano oscillator.*

Keywords*: Platinum thin film, RF sputtering, Spin-orbit coupling, Spin Hall voltage.*

1. INTRODUCTION

The phenomenon of Spin Hall Effect (SHE) was discovered by D'yaknov and Perel in 1971. Theoretical proof of impurity scattering responsible for this effect was given by Hirsch [1] and this was further extended to diffusive transport by Zhang. In normal metals SHE is induced by spin-orbit scattering due to impurities or defects [2-5]. The unpolarized charge current flowing in a nonmagnet generates the transverse spin current that results into spin accumulation at the side edge of nonmagnetic surface when spin current flows in a nonmagnet it induces the transverse charge current and generates the charge accumulation [6, 7]. In direct Spin Hall Effect, when a charge current density J_e flows along the length of metallic thin film a spin current (J_s) of magnitude ($\hbar J_s$ /2e) flows in transverse direction generates spin Hall Voltage.

Platinum is one of the most important paramagnetic metal that exhibit highest spin-orbit scattering and shows Spin Hall Effect (SHE). Spin Hall Effect is the transverse flow of spin current when an electric field is applied. It was first proposed in semiconductors [8, 9]. This effect helps to control spins in nonmagnetic materials even in the absence of applied magnetic field. Spin-orbit interactions in non-magnetic materials converts a charge current into a spin current and vice versa these are known as "direct" and "inverse" spin Hall Effect[10, 11]. It can be easily understood as spatial separation of spin-up and spin down electrons occurs by spin-orbit interaction. When an electric current flows, spin of these charges interact with orbit of impurity atom as a result there is spin- orbit interaction as a result transverse flow of spin current is produced in the sample. The spin-up and spin-down electrons flow in opposite direction generates a gradient potential. Now a days lots of work are being done on metallic Spin Hall Effect [12-14]. Among metallic system platinum shows remarkably large SHE compared to aluminium and copper. This is because of strong spin-orbit coupling in platinum. In present paper effect of thickness of platinum thin film on spin Hall voltage has been investigated. It has been observed that the resistance of the platinum film increases by reducing the thickness of the film. The role of spin-orbit interaction in spin Hall voltage has been analyzed.

2. EXPERIMENTAL

Thin films of varying thickness of platinum were deposited on silicon substrate by RF sputtering. The base pressure of the chamber was 5×10^{-6} mbar. Deposition of Pt film has been carried out in Argon pressure 2×10^{-2} and substrate temperature was kept at 300^{o}C during film deposition. Thin films were deposited at 30 watt RF power. For varying thin film thickness, deposition time was kept 30 s, 45 s and 60 s by using mask of dimension 5 mm x 0.8 mm on silicon substrate. Thickness of the film was measured by stylus profilometer.

Charge current in microampere has been applied at longitudinal side of Pt film and induced voltage due to spin current has been measured in transverse direction. The schematic diagram showing Pt thin film along with charge current and measured voltage direction has been shown in Fig. 1. Charge current has been applied by using Keithley source meter.

3. RESULTS AND DISCUSSION

When the charge current is applied in Pt film along X direction then due to the presence of impurities and defects spin-orbit coupling occurs and a transverse spin current is developed at room temperature. Due to spin-orbit coupling, side jumping and skew scattering spin up and spin down electrons get separated and moves in transverse direction to the applied charge current. Flow of spin up and spin down electrons in opposite direction generates spin current. Due to the flow of spin current a voltage is developed transverse to charge current that is known as spin Hall voltage.

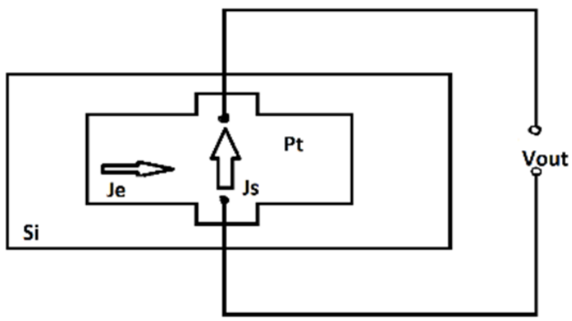

Fig. 1: Schematic diagram showing voltage output due to Spin Hall Voltage.

The schematic diagram Fig. 1 shows the applied charge current and developed voltage transverse to charge current

Quantum mechanically let the number of spin electrons $q_{\uparrow\downarrow}$ be created by the separation of spin up and spin down electrons.

$q_{\uparrow\downarrow}=q_{\uparrow} + q_{\downarrow}$

where $q_{\uparrow}$ and $q_{\downarrow}$ are up-spin and down-spin respectively. In case of paramagnetic nonmetal like platinum Spin Hall Voltage (V_{SH}) is created by the separation of spin up and spin down electrons when current density J_x flows along the length Hall voltage would be generated along the width W of sample and R_H anomalous Hall coefficient Hence spin Hall Voltage become

$V_{SH} = q_{\uparrow\downarrow} R_s W J_x \mu_B$

where μ_B is Bohr magnetron.

Thickness of paramagnetic Pt thin film on silicon substrate with varying deposition time has been measured 60 nm, 45 nm and 30 nm. The resistance of thin films has been determined by applying a constant current to the films as 20 Ω, 70 Ω, 1.2 kΩ respectively. The resistance of the film increased with decreasing film thickness. When thickness of the film decreases the quantum effects of impurity as potential scattering centers for conducting electrons get more pronounced. By reducing thickness of metallic film surface conduction has dominant effect. Thus by reducing Pt film thickness scattering of conduction electrons with impurity increases thus resistance of thinner film increased. The scattering between electron and impurity atom/vacancy potential is known as spin-orbit scattering which is spin dependent. A constant current density 1.5 mA/cm^3 has been applied to the varied thickness of Pt films. A DC voltage has been measured transverse to the applied current which is known as spin Hall voltage. The spin Hall voltage has been obtained 1.2 mV, 1.9 mV and 4.2 mV for 60 nm, 45 nm and 30 nm Pt thin film respectively. The produced spin Hall voltage and resistance variation with thickness of Pt film has been shown in Fig. 2. It is suggested that with reducing thickness spin-orbit interaction increases in paramagnetic Pt thin film which in turn increased spin Hall Voltage.

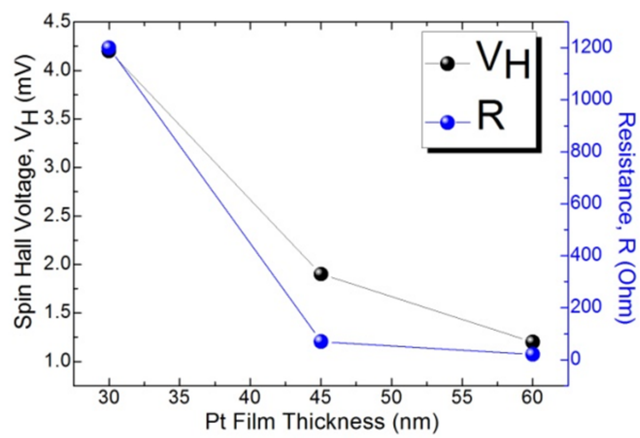

Fig. 2: Platinum film Thickness versus film Resistance and Spin Hall Voltage.

4. CONCLUSION

Paramagnetic platinum thin films of varying thickness has been deposited by RF sputtering deposition technique. It has been found that the resistance of metallic Pt film increases with decreasing thickness. Spin Hall voltage has been found to increase with decreasing Pt film thickness. Highest 4.2 mV spin Hall voltage has been obtained in the thinnest 30 nm Pt thin film. The paramagnetic metallic Pt thin film exhibits the maximum spin-orbit scattering which produce more spin current has been used in spintronic devices. It has a potential application in low power microwave nano oscillator.

5. ACKNOWLEDGEMENTS

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