Bismuth thin films: polar angle and ion fluence

A.S.Bhattacharyya[1, 2*] R. Praveen Kumar[1], Rishideo Kumar[1], Vikrant Raj[1]

[1]Centre for Nanotechnology and [2] Centre of Excellence in Green and Efficient
Energy Technology (CoE-GEET)
Central University of Jharkhand, Ranchi – 835 205, India,

*e-mail: 2006asb@gmail.com ; arnab.bhattacharya@cuj.ac.in

Bi has shown major physical phenomena in the past like de Haas-van Alphen effect [1], quantum size, confinement effect [2], quantum linear magnetoresistance [3], peculiar superconductivity [4], and possibly fractional, quantum Hall effect [5]

We started with our established model of sputtering and deposited atomic layers of Bi as a function of deposition time and current density. The input parameters were molar weight of Bi (209 g/mol), its atomic radius (1.67 Å) and density (9.8 g /cm^3) [7, 8]. The results showed a linear variation of atomic layers with deposition time and a higher rate of deposition with increase in current density as shown in Fig 1(a) with the highest and lowest slope plots for j = 25 and 1 mA / cm^2 .

The computational model gave us 250 (25 ×10) values of atomic layers for 10 values of deposition time (t = 1to 10s) and 25 values of current density (j = 1 to 25 mA / cm^2) the distribution of which is shown in Fig 1(b). The plot can be seen to be a combination of 25 similar shaped plots each corresponding to a particular current density value. The plots were found to be steeper for higher current density values suggesting higher rates of deposition as also found previously. The number of atomic layers multiplied by the atomic diameter gives us the film thickness. The thickness varied from few nm to 500 nm (Fig 2).

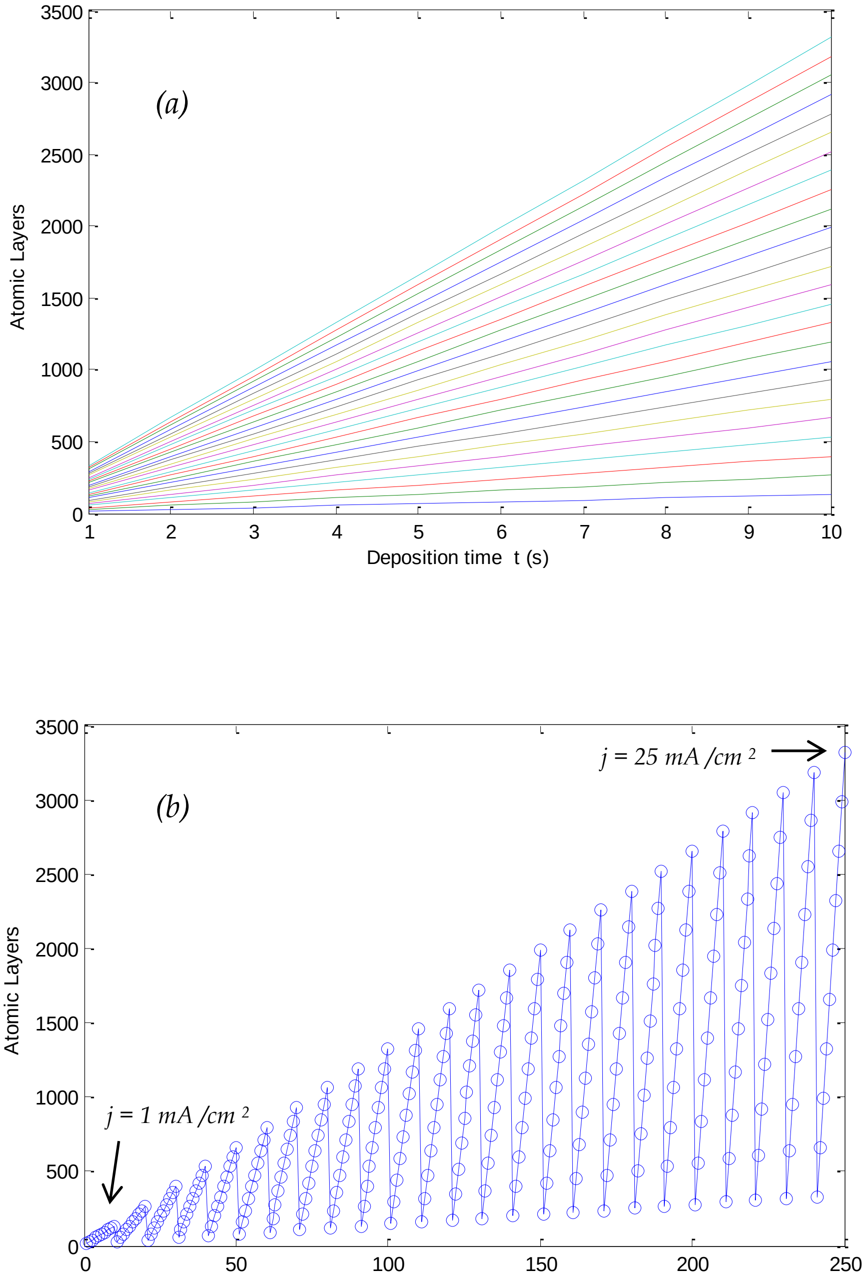

Fig 1: Bi atomic layers deposited as a function of deposition time and current density

Deoli et. Al have shown the ion fluence dependence of the total sputtering yield and differential angular sputtering yield of Bi. An attempt was made to computationally mock the sputtering process and deposit Bismuth films and study the effect of polar angle and ion fluence. Experimentally it has been shown that the differential and total sputtering yield for Bi by normally incident 50 keV Ar+ ions increases with increasing ion fluence for the measured fluence range [6]. We tried to match the experimental results and moved a step further showing the variation of Atomic Layer deposition with polar angle.

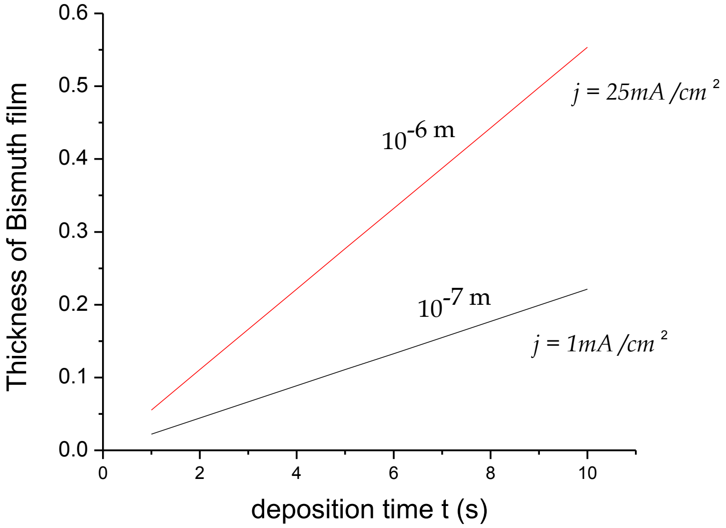

Fig 2: Deposition rate at two different current densities

In our model we then used the differential sputtering yield instead of the sputtering yield and observed specific polar angles giving higher deposition rate (Fig 3). The angles were 0 degree and 60 degree. Sputtering peaks around 60 degree which is an established fact, however the angle 0 degree can be considered as error as there is possibility of the freed atoms to be knocked deeper in to the material.

Bi thin films deposited by MBE showed variation in electrical conductance with thickness and temperature. A unique feature of showing insulating properties in the bulk whereas conducting properties called Topological insulators (TI) are helpful for spintronic devices. [9]. Bi thin films are interesting examples where a topologically trivial system becomes non-trivial solely due to the reduction of thickness [10]. The topological states have been also investigated using first principle calculations [11].

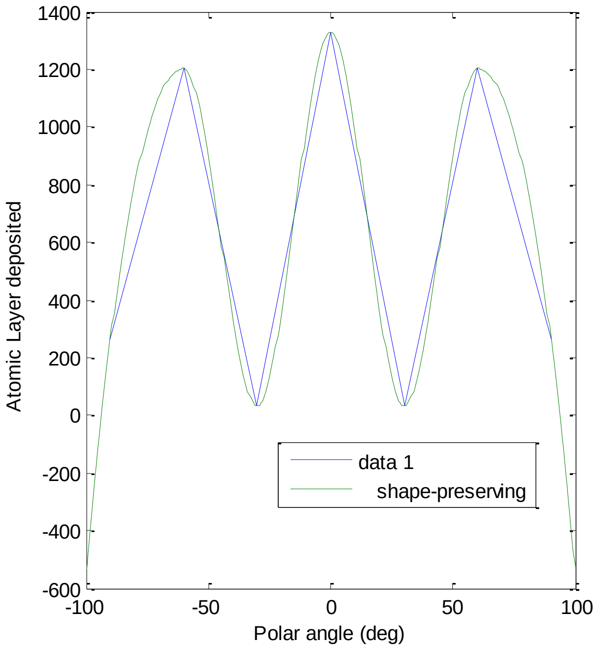

Fig 3 : Atomic layers of Bi at different polar angle

Bismuth Selenide (Bi_2Se_3) and Bismuth Telluride (Bi_2Te_3) are very promising Tis which have sown oscillatory magnetoresistance due to Shubnikov-de Haas Effect [12]. Combining TIs and superconductors give Marjorana Fermions which possess both particle and antiparticle properties. They have application in Quantum Computing [13]

Reference

1. W. J. de Haase and P. M. van Alphen, Proc. Acad. Sci.33, 1106 (1930).
2. Y. F. Ogrin, V. N. Lutskii, and M. I. Elinson, JETP Lett.7, 71 (1966).
3. A. A. Abrikosov., Europhys. Lett.49, 789 (2000).
4. W. Buckel and R. Hilsch, Z. Phys.138, 109 (1954).
5. K. Behnia, L. Balicas, and Y. Kopelevich, Science 317, 1729 (2007)

6. Naresh T. Deoli, Lucas C. Phinney, Duncan L. Weathers, Nuclear Instruments and Methods in Physics Research B 332 (2014) 286–289

7. AS Bhattacharyya, S Kumar, S Jana, PY Kommu, K Gaurav, S Prabha, VS.Kujur, P.Bharadwaj, Sputter based Epitaxial Growth and Modeling of Cu/Si Thin Films, *Int. J. Thin. Fil. Sci. Tec* 4 (3), 2015,173-177

8. A.S.Bhattacharyya, Sweta Prabha, Vidya S. Kujur, P. Bharadwaj, Computation modeling of epitaxial deposition of Tungsten thin films J. Nano science Engineering & Trends. *2(1), 2016*,1-5

9. Shunhao Xiao, Dahai Wei, and Xiaofeng Jin, Bi(111) Thin Film with Insulating Interior but Metallic Surfaces Phys. Rev. Lett. 109, 166805 – Published 17 October 2012

10. Kai Zhu, Lin Wu, Xinxin Gong, Shunhao Xiao, Shiyan Li, Xiaofeng Jin, Mengyu Yao, Dong Qian, Meng Wu, Ji Feng, Qian Niu, Fernando de Juan, Dung-Hai Lee arXiv:1403.0066 [cond-mat.mes-hall] 2014

11. Wang D, Chen L, Liu H, Wang X, Cui G, Zhang P, Zhao D, Ji S. Topological states modulation of Bi and Sb thin films by atomic adsorption Phys Chem Chem Phys. 2015 Feb 7;17(5):3577-83. doi: 10.1039/c4cp04502e.

12. Justin Kelly Magnetotransport of Topological Insulators: Bismuth Selenide and Bismuth Telluride 2011 NSF/REU Program, Physics Department, University of Notre Dame

13. Ziga Kos, Topological Insulators, University of Ljubljana, June 24, 2013

MATLAB Codes

```
%ATOMIC LAYERS //Bi
for S=0.1:0.1:2.0;
E=50e3;
M=209;
r=9.8;
NA=6.02e26;
e=1.6e-19;
rBi=1.67e-10;
for jp=1:25;
zt = M/(r*NA*e)*S*jp;
zt=zt/100;
t=1:10;
AL(t,jp)=t*zt(:)/(2*rBi);
x=0.3;
k=1.4e-23;
T=300;
L=k*T;
ALd=AL*exp(-x\L);
end
end
```

```
% \\ Using differential sputtering yield (dS) instead of S
W =[ -90   -60   -30     0    30    60    90];
E=50e3;
M=209;
r=9.8;
NA=6.02e26;
e=1.6e-19;
rBi=1.67e-10;
for i=1:7;
for jp=10:50;
zt = M/(r*NA*e)*cos(W(i))^2*jp;
zt=zt/100;
t=1:10;
AL(i,t,jp)=t*zt(:)/(2*rBi);
x=0.3;
k=1.4e-23;
T=300;
L=k*T;
ALd=AL*exp(-x\L);
end
end
```