Electron Transport in Silver Silicon Composite Film

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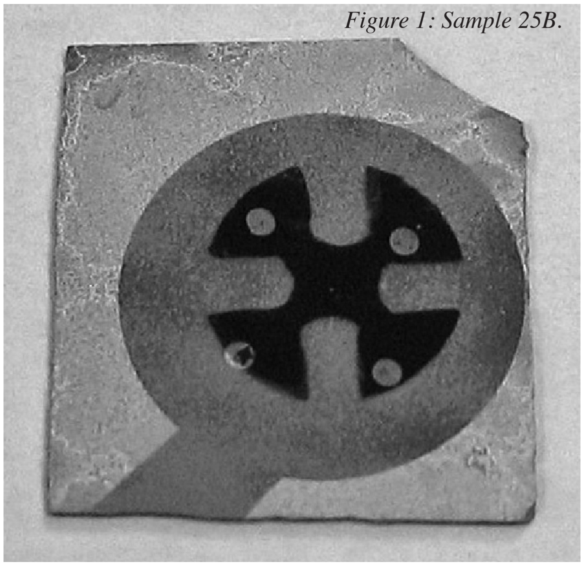
Abstract

Composite films of silver (Ag) nanoparticles embedded in an n-doped silicon (Si) matrix exhibit strong photo responses when exposed to infrared spectrum, especially in the 1-15 μm wavelength range. The focus of this project is to quantify the Hall effect on a 3 μm thick composite film composed of 18% Ag grown on a highly resistive Si substrate. The measured Hall current is related to the electron mobility and reflects the responsivity of the future infrared detector. Samples were created via magnetron co-sputtering at 550°C using Argon plasma at 3.5 mTorr. Four ohmic contacts of chromium (Cr) and gold (Au) were evaporated on the sample, using e-beam and thermal deposition followed by rapid thermal annealment, to employ the Van Der Pauw method of Hall measurement. Hall measurements were taken at the National Institute of Standards and Technology between 77 K and 300 K.

Introduction

Silver nanoparticles display strong photo responses to infrared spectrum. To create a device that takes advantage of this characteristic, Ag will be co-sputtered with highly n-doped Si to form a matrix with embedded Ag nanoparticles. In order to fabricate this device, we must characterize its responsivity, electron mobility and potential lifetime. Fortunately all this can be extracted from measurements of the Hall currents, which is a direct measurement of the mobility and rapidity of the electrons in the material. Essential to the film are isolated small non-chemically bonded Ag nanoparticles; isolated to avoid shorts, small to increase the surface area and response strength, and non-chemically bonded to avoid unwanted silicides. To avoid the silicides, we made depositions at 550°C which is low enough to prevent silicides and high enough that we get our silicon in crystal form. Taking into account the other specifications, this project aimed to accurately sputter a 3 μm thick composite film of 18% Ag, 82% n-doped Si onto a Si substrate.

Figure 1: Sample 25B.



Experimental Procedure

Our Ag and n-doped Si (resistivity: 1-5 Ωcm) targets were placed in the Kurt J. Lesker CMS-18 Magnetron Plasma co-sputtering system. This system uses argon plasma and using different voltages can co-sputter two targets at varying rates. For both of our trials, 25A and 25B, the deposition temperature was 550°C and the Ar pressure was 3.5 mTorr. Both depositions ran for precisely 2.5 hours. Our first sample 25B had the following deposition specifics: base pressure of $2.7*10^{-7}$ Torr, Ag power supply of 12W (~ 260V across target), Si power supply of 330 W (~ 470V). Our second sample, due to a realization that 25B had too much Ag, had a much lower Ag voltage: base pressure of $5.0*10^{-8}$ Torr, Ag power supply of 7W (152V), same Si power supply. After deposition, four ohmic contacts had to be placed on the film for the future Hall measurements. To achieve this, we evaporated a 200Å layer of chromium followed by a 1500Å layer of gold, using e-beam and thermal evaporation respectively. The sample then underwent thermal annealing at 600°C for 30 seconds. The final product is shown in Figure 1.

At this point, we went to make the Hall measurements using the Van Der Pauw method. Detailed info on the exact specifics of this technique can be found at http://www.eeel.nist.gov/812/hall.html. The key variable defined by this experiment is ΣV_i which is the sum of all the positive magnetic field voltages minus the sum of all the negative field voltages (we used a magnetic field of 8000 Gauss). This value plugs into $n_s = ((8*10^{-8})IB)/(q* \Sigma V_i)$ to get the number of mobile carriers. Finally this value, along with the average resistivity, R_s, gives us the electron mobility of $\mu = (R_s{*}qn_s)^{-1}$. We took these mobility measurements at different temperatures from 77K to 290K to define the optimal operating temperature.

Results and Discussion:

Figures 2 and 3 display the resistivity and electron mobility vs. temperature for both samples. As can be seen from Figure 3, the resistivity of sample 25B is far too low, implying too much silver. Later Rutherford back-scattering tests showed that indeed sample 25B was 22.5% Ag and that our corrective measures resulted in 11% Ag in 25A. Thus sample 25B was relatively useless for this project.

25A was more hopeful, in that it displayed the expected mobility vs. temperature relationship; initially a positive relationship due to decreased impurity scattering, later to taken over by a negative relationship caused by lattice vibrations. The final issue we took with sample 25A was how low the Hall mobility was, which should have been in the 10^3, 10^4 range. This could probably be solved by using a more highly doped Si target (of resistivity around 0.001-0.006 Ωcm) which was our original intent (but the target cracked). Also more accurately attaining 18% Ag would help in this matter.

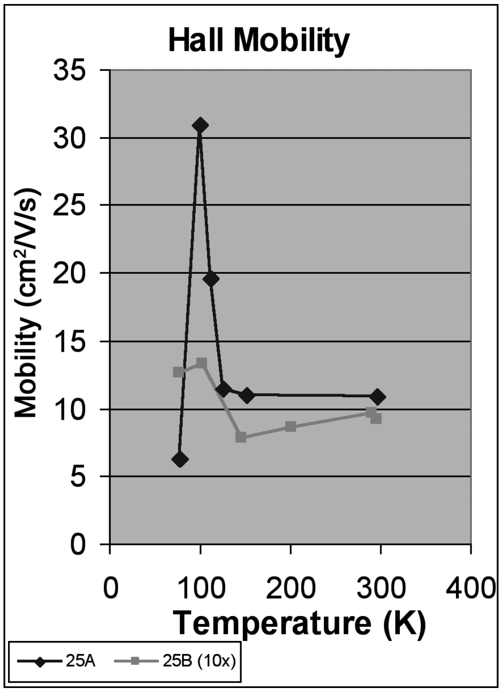


Figure 2: 25A, 25B Hall mobility.

Future Work

For the future creation of an infrared detector, more characterization is required. Specifically, the measurement of the responsivity of the device to different incident wavelengths at varying operating voltages. After that, this project only needs optimization of the fabrication process and creating the final product.

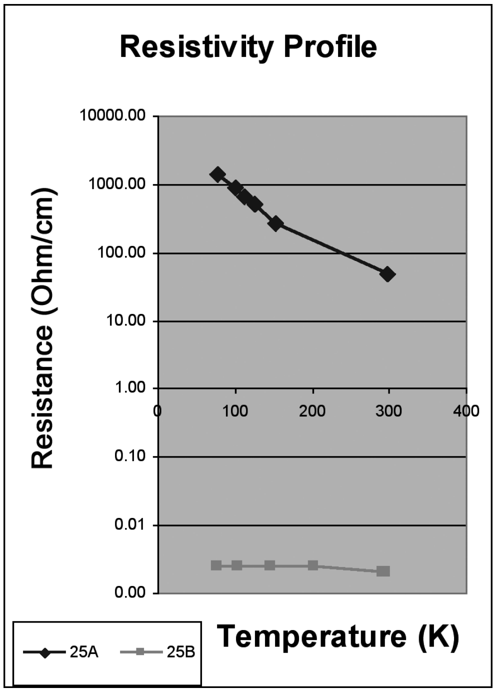


Figure 3: 25A, 25B Resistivity profiles.

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References

[1] Shur, Michael. Physics of Semiconductor Devices. Prentice Hall. NJ, 1990.

[2] Sze, Simon. Physics of Semiconductor Devices. Wiley-Interscience. 1981.

[3] Zeghbroeck, Bart Van. "Principles of Semiconductor Devices" http://ece-www.colorado.edu/~bart/book/ 2004.