Magnetron Sputtering and Characterization of Ag-Si for Infrared Photodetectors

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Abstract:

Silver and silicon (Ag-Si) composite films are the first metal-semiconductor composite system to demonstrate a response to radiation over the 1-14 μm wavelength range from liquid nitrogen to room temperature. Magnetron co-sputtering at 550°C was used to deposit 1 μm thick Ag/n-Si films with Ag concentrations ranging from 13%-23% onto highly resistive n-Si (111) substrates. The Van der Pauw method was used to characterize the transport properties of these films. Room temperature resistivity measurements on the order of 10-1Ω·cm are higher than expected of only highly doped n-Si. Lower resistivity was recorded with higher Ag concentration. Measured mobility of around 1 cm^2/V·s was observed at room temperature. This low mobility is due to the high dopant concentration in the silicon. Resistivity and mobility measurements are different from values of only highly doped n-Si. Carrier concentration at room temperature is consistent with highly doped n-Si for lower Ag concentration, but generally increased with Ag concentration. While the behavior of carrier concentration is not currently fully understood for Ag/n-Si systems, the above results were verified at the National Institute of Standards and Technology in Gaithersburg, MD.

Introduction:

Ag/n-Si composite films are the first metal-semiconductor composite system to demonstrate a response to radiation over the 1-14 μm wavelength range from liquid nitrogen to room temperature. With an electric field of 2×10^6 V/cm applied to a sample with the composite film, previous studies have shown efficiencies of up to 35% depending on incident wavelength [1]. Magnetron co-sputtering was used to deposit silver and highly doped n-type silicon simultaneously. A deposition temperature of 550°C was high enough to ensure that the deposited silicon was crystallized [2]. This method of deposition allows the silver to form small nanoparticles that are embedded within the silicon crystal lattice. Before devices can be made using this technique, the transport properties must be measured. Hall effect measurements were used to characterize these properties.

Experimental Procedure:

A Kurt J. Lesker CMS-18 Magnetron Plasma co-sputtering system was used with one silver target and one highly doped n-type silicon target. High resistivity (2000-3000 Ω·cm) n-type Si (111) wafer was used as the substrate. To grow each sample, a constant temperature of 550°C and with 3.5 mTorr argon pressure was used for the 50 minute deposition. The sample was rotated at 20 rpm to help ensure a uniform film. A power of 330W was applied to the silicon target for all runs. The power applied to the silver target was changed for each run depending on the desired concentration of silver and can be seen in Figure 1.

Sample	power to Ag target	Ag concentration
74a	12 W	22% - 23%
74b	9 W	16% - 17%
75a	7 W	13% - 14%

Figure 1

Hall measurements were made using the MMR Technologies, Inc., Hall measurement system. This system uses the Van der Pauw technique to measure resistivity, Hall coefficient, carrier mobility, and carrier density [3]. The system was used to take measurements at temperatures from 80K up to 500K with a magnetic field of 10kG. Chromium and gold were deposited to form the ohmic contacts.

Results and Discussion:

Using the given sputtering parameters, the resulting deposition had a thickness of 1 μm. The results of varying the power to the silver target on the concentration of silver can be seen in Figure 1. These concentrations were measured using electron dispersive spectroscopy (EDS). Each sample appeared to have low resistivity of less than 10 Ω·cm at liquid nitrogen temperature. The general decreasing trend of

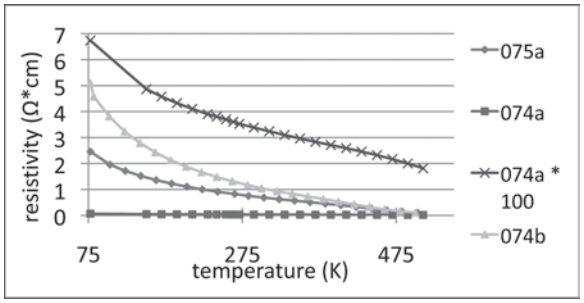

Figure 2

the resistivity with increasing temperature, as seen in Figure 2, is similar to the behavior of silicon and was expected due to the separation of silver nanoparticles by silicon crystal. It should be noted that sample 74a, which had the highest silver concentration displayed the lowest resistivity. The magnitude of the carrier mobility generally increased with temperature as seen in Figure 3.

All samples were measured to have very low carrier mobility of much less than 1 $cm^2/V\cdot s$ at temperatures around liquid nitrogen temperature. This mobility increased slowly to about 1 $cm^2/V\cdot s$ at room temperature. This was expected due to overlapping depletion regions at the silver-silicon interfaces.

Samples 74b and 75a, with lower concentrations of silver, displayed carrier densities consistent with the highly doped n-type silicon used in deposition over temperature ranges from liquid nitrogen to room temperature. Sample 74a had a higher silver concentration and showed a significantly higher carrier density. For each sample, the carrier density decreased with increasing temperature as seen in Figure 4.

While the behavior of the carrier density and mobility in this composite film is not fully understood, measurements made at the National Institute of Standards and Technology (NIST) agreed with the data found in this study.

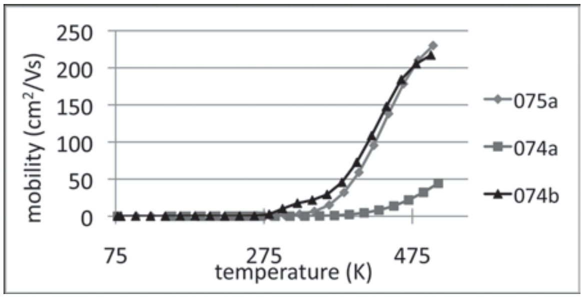

Figure 3

Future Work:

Future work will include the measurement of responsivity of this silver-silicon composite film for different wavelengths of incident radiation. Further analysis of the data found in this study may help find the optimal conditions under at which future devices may operate.

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References:

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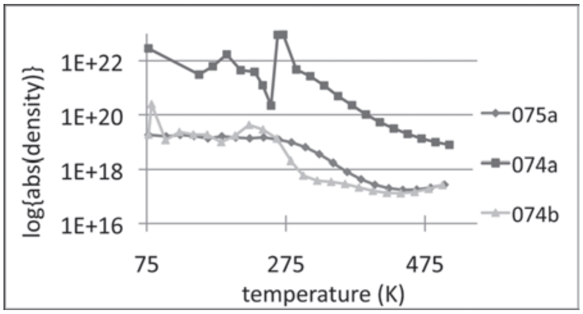

Figure 4