Phase Transformations in Metal Contacts to $In_{0.53}Ga_{0.47}As$ Nanowires

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Abstract:

III-V compound semiconductors such as indium gallium arsenide (InGaAs) are being studied for use in nanoscale transistors as faster, more energy-efficient alternatives to silicon. In order to make use of an InGaAs channel, it must have low-resistance contacts to its source and drain regions. To facilitate the development of appropriate source-drain contacts, phase transformations between InGaAs nanowires and nickel (Ni) and palladium (Pd) metals were studied. Nanowires were etched from an InGaAs film on an indium phosphide substrate, and a metal layer was sputtered onto the sample. Analysis of scanning electron microscopy images and energy dispersive x-ray spectroscopy data collected from annealed samples showed no lateral diffusion of either metal into the nanowires. Pd-sputtered samples showed wire roughening under and close to the pads, suggesting that the presence of the metal catalyzed decomposition of the wires. Furthermore, roughening was more pronounced in samples annealed at lower temperatures, suggesting multiple mechanisms for the decomposition of InGaAs wires in the presence of Pd.

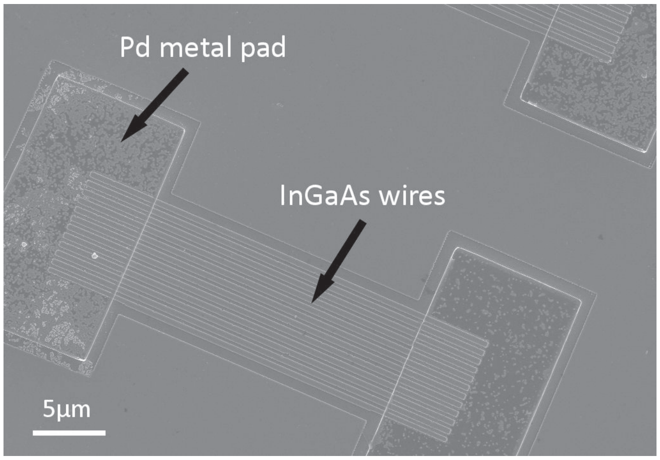


Figure 1: An SEM of a sample with Pd pads after annealing at 200°C for two minutes. The metal pads are deposited on the ends of the nanowires to facilitate analysis of wires in contact with the pads.

Introduction:

Past research in computational electronics has been focused on maximizing the number of silicon transistors able to fit on a substrate. However, as these devices enter the nanoscale and short channel effects become significant, it becomes difficult to increase the density of silicon transistors. Researchers are now looking at increasing the speed and energy-efficiency of transistors. III-V compound semiconductors, such as InGaAs, have higher carrier mobility and faster frequency response than silicon [1]; using these materials as the channel material allows transistors to operate at higher speeds and at lower voltages.

In order to fully utilize such transistors, low-resistance contacts to the source and drain must be realized. Research in thin film InGaAs have shown that both nickel and palladium, when annealed in temperatures at or above 200°C, diffuse into InGaAs to form an intermediate, low-resistance phase [2, 3]. In this project, reactions between nickel and palladium with InGaAs nanowires were studied to better understand phase formations at the nanoscale.

Experimental Procedure:

Nanowires were fabricated from a film of 50 nm of n-type $In_{0.53}Ga_{0.47}As$ on an indium phosphide substrate. Nanowires of varying widths (150 to 700 nm) were defined using electron beam lithography, and then wet-etched using a solution of citric acid and hydrogen peroxide. Then, 75 nm of the contact metal was sputtered onto the samples and lifted off to reveal metal pads at the ends of the nanowires, as shown in Figure 1.

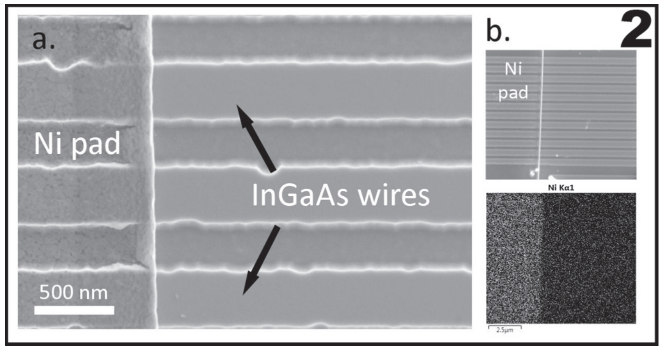
The sample sputtered with Ni was annealed at 375°C for two minutes, characterized, and then annealed further for three minutes for a total of five minutes. The samples sputtered with palladium were treated in the same way, but with one sample annealed at 375°C and another at 200°C. A control sample of nanowires without metal pads was also annealed at 200°C for two minutes. All annealing was done in an argon atmosphere.

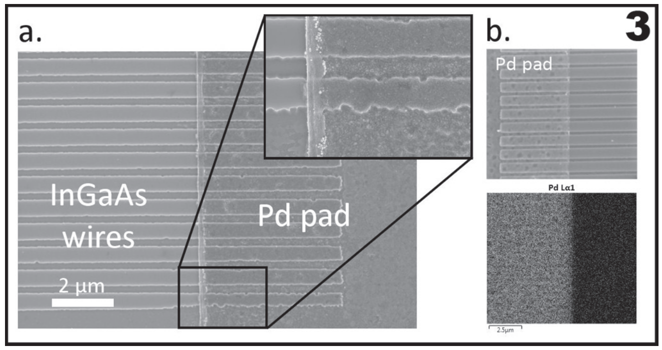
Results and Conclusions:

In the control sample, no wire degradation was seen in scanning electron microscopy (SEM), showing the thermal stability of the nanowires. SEM images of Ni-sputtered sample annealed for two minutes showed no sign of phase formation in the nanowires outside the Ni pads. Energy dispersive x-ray spectroscopy (EDS) elemental maps also showed no signal of nickel diffusing laterally into the wires. No significant degradation of nanowires below or outside of the pads could be seen. SEM images and EDS maps taken of the same sample after further annealing showed no differences from data taken after two minutes of annealing.

Figure 3a shows an SEM image of the Pd-sputtered sample annealed at 375°C. Unlike the Ni-sputtered samples, these wires show roughening of edges under the pads, near the ends of the wires. The sample annealed at 200°C shows even more decomposition of the wires. Under the Pd pads, the wires are disintegrating and breaking into pieces, while wires edges are significantly roughening immediately outside of the pads. EDS maps for either samples show no significant Pd signal from outside the contact pads. Again, the data obtained from the samples at annealing times of two minutes and five minutes were the same in terms of wire roughness and EDS signals. The SEM images suggest that the presence of Pd is affecting the nanowires, but no Pd can be detected in them. It is possible that the decomposition of InGaAs in the vapor phase is catalyzed by the presence of Pd.

In summary, neither the Ni-sputtered sample nor the Pd-sputtered sample showed signs of metal diffusing into the InGaAs wires to form intermediate phases. In the case of the Pd-sputtered samples, the wires under and close to the contact pads decomposed. This phenomenon is not seen in the Ni-sputtered sample and suggests that the presence of the palladium is the cause for the wire disintegration. Furthermore, this effect was more prominent in the sample annealed at 200°C than in the sample annealed at 375°C.





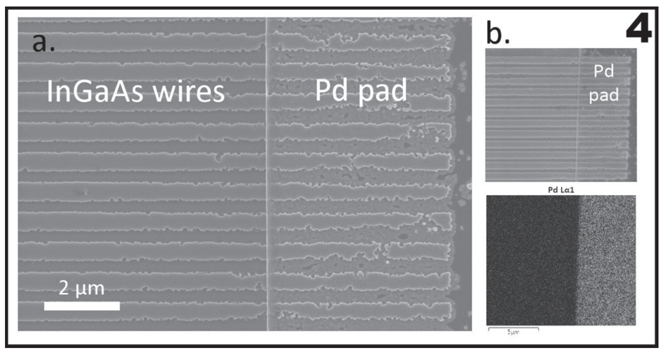


Figure 2, top: InGaAs wires with Ni metal pad after annealing at 375°C for two minutes. a) A close up SEM of the sample. b) The electron image and the corresponding EDS map for Ni signal.

Figure 3, middle: InGaAs wires with Pd metal pad after annealing at 375°C for two minutes. a) An SEM image of the sample. b) The electron image and the corresponding EDS map for Pd signal.

Figure 4, bottom: InGaAs wires with Pd metal pad after annealing at 200°C for two minutes. a) An SEM image of the sample. b) The electron image and the corresponding EDS map for Ni signal.

Future Work:

In order to confirm the data obtained, the fabrication, treatment, and analysis of nanowires with palladium pads must be repeated and the SEM and EDS images compared to pre-annealing data. To determine the identity of new phases formed in the palladium case, sample cross sections should be studied in transmission electron microscopy.

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