Investigation of Temperature-Dependent Electrical Properties in Delta-Doped Silicon

Ramyapriya Krishnasamy[1], Zixin Zhai[1], Alexandra Joshi-Imre[1], John Randall[2], Walter Voit[1] and James Owen[2]

[1]The University of Texas at Dallas; [2]Zyvex Labs, Richardson

Delta-doped silicon, characterized by sharp doping profiles and high carrier concentrations, has applications in many areas, including **cryogenic electronics** and **quantum computers** [1]. Understanding the resistance behavior at low temperatures is crucial for the effective utilization of delta-doped layers in these applications. This study provides a comparative analysis of temperature-dependent resistance in delta-doped and undoped silicon structures, enabling a deeper understanding of delta-doping's influence at cryogenic temperatures.

Palladium silicide (Pd_2Si) is used as the contact material because of its ability to form reliable, low-resistance electrical contacts with delta doped silicon with 30 nm epitaxial silicon, as demonstrated in previous research [2]. Contact resistance is extracted using the transfer length method (TLM), which involves analyzing resistance across contact pads with varying distances. Preliminary results reveal distinct resistance trends between samples with and without delta-doped layers, providing insights into the performance of delta-doped silicon across a range of temperatures.

The findings underscore the effectiveness of delta-doped silicon in maintaining low resistance at cryogenic temperatures, which is essential for its integration into advanced electronic systems. As illustrated in Figure 1, bulk conduction dominates the overall resistance at room temperature. However, as the temperature drops, freeze-out effects become noticeable around 75 K. At this point, the resistance of silicon without a delta-doped layer rises sharply to several hundred ohms, while the p-type delta-doped sample retains much lower resistance. Notably, the temperature-dependent resistance data reveals that the delta-doped sample transitions to metallic conduction below 40 K, with resistance values of approximately 16 ohms.

Based on the data so far, the contact resistivity stabilizes at approximately 3000 ohm·μm^2 below the bulk freeze-out temperature, suggesting a very low-resistance contact with the delta layer. Additionally, to properly assess the linear increase in resistance with distance, more distance variations are needed in future experiments.

Future experiments will investigate the impact of different substrate types, variations in delta dopant species, and the influence of the epitaxial layer on resistance versus temperature behavior and contact resistance. Additionally, Hall measurements will be conducted to gain deeper insights into the electrical and carrier transport properties of delta-doped silicon structures.

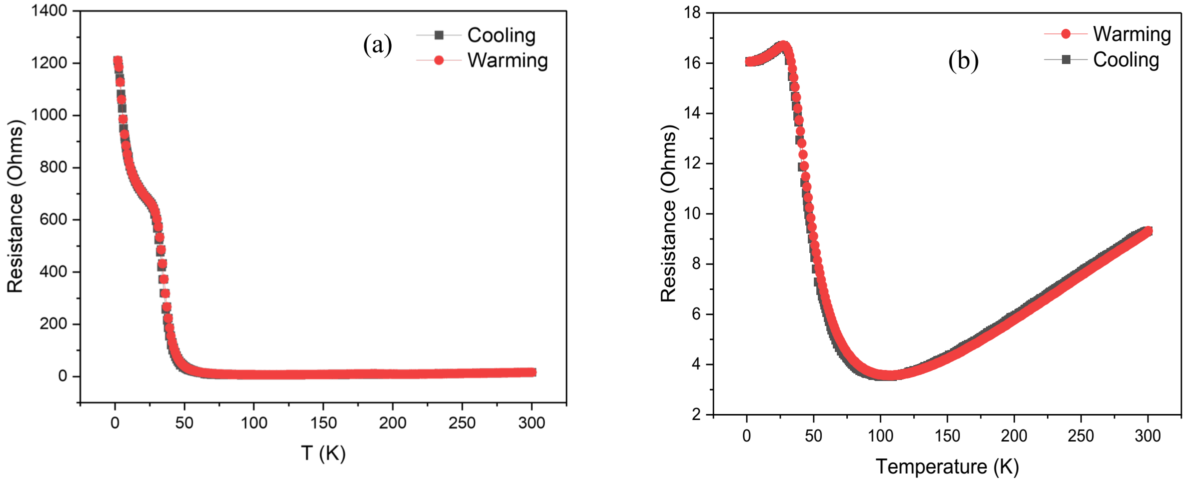

Fig 1: Resistance vs temperature curves measured between contact pads at 575 µm distance. Cooling and warming cycles refer to resistance measurements from 300 K to 2 K and the subsequent increase back to 300 K, respectively. (a) a p-type substrate (resistivity: 1 Ω·cm) covered by a 30 nm epitaxial silicon layer. (b) p-type substrate (resistivity: 1 Ω·cm) with a p-type globally delta-doped layer enclosed within the 30 nm epitaxial silicon layer.

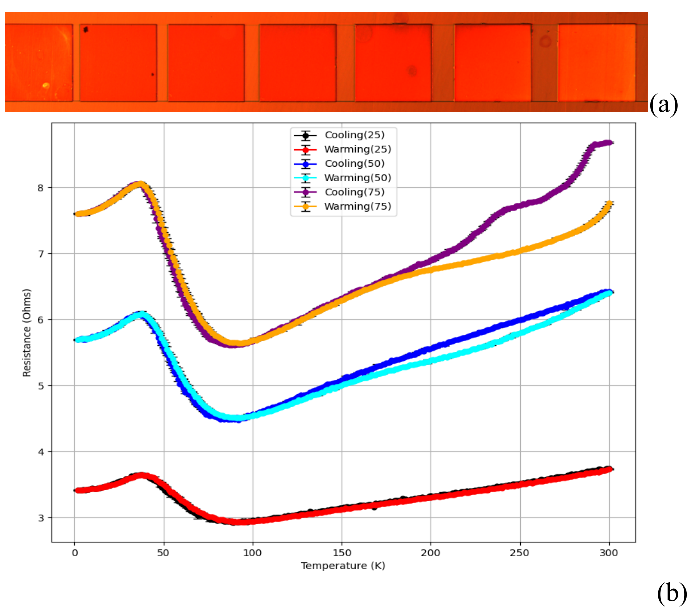

Fig 2: (a) Optical microscope image of the linear TLM structures used for the extraction of contact resistances. The size of each square contact pad is 500 microns by 500 microns.

(b) Temperature-dependent resistance of a p-type globally delta-doped layer on an n-type substrate for the first three sets of contact pads, spaced at distances of 25 µm, 50 µm, and 75 µm.

References

1. F. A. Zwanenburg, A. S. Dzurak, A. Morello, M. Y. Simmons, L. C. L. Hollenberg, G. Klimeck, S. Rogge, S. N. Coppersmith, and M. A. Eriksson, Silicon quantum electronics, Rev. Mod. Phys. 85, 961 (2013).

2. Schmucker, S. W., Namboodiri, P. N., Kashid, R., Wang, X., Hu, B., Wyrick, J. E., Myers, A. F., Schumacher, J. D., Silver, R. M., & Stewart Jr., M. D. (2018). Low-Resistance, High-Yield Electrical Contacts to Atom Scale Si:P Devices Using Palladium Silicide. *Physical Review Applied, 11*(3), 034071. https://doi.org/10.1103/PhysRevApplied.11.034071