Superconducting Gallium-Hyperdoped Germanium from Pulsed-Laser Melting

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Superconducting doped group IV materials have been gaining substantial experimental interest over the last two decades as they offer an attractive means for integrating semiconductor and superconductor-based devices on a single chip. The superconducting transition occurs when the semiconductor is doped with p-type dopants far beyond the concentration required to induce an insulator-to-metal transition (IMT). Typical values for p-type doping to achieve this are around several atomic percent, which is far beyond the solid solubility limits of the dopants in group IV semiconductors. As such, they will typically need to be fabricated by highly non-equilibrium techniques, including but not limited to, ion implantation, flash lamp annealing (FLA), and/or pulsed laser melting (PLM), to quench in the high concentrations of dopants.

Significant amount of experimental work has already been conducted on superconductivity in boron-doped diamond [1], boron-doped-silicon carbide [2], and recently, aluminium-doped silicon [3]. On the other hand, there is much less literature on germanium-based materials, most likely because of weaker theoretical predictions for superconductivity [4]. Nevertheless, there have been reports of superconductivity observed experimentally in aluminium- and gallium-hyperdoped germanium fabricated from ion implantation followed by FLA [4, 5], with peak dopant concentrations of 6 at.% and 10 at.%, and Tc of ~0.15 and ~0.45 K for Al- and Ga-hyperdoping, respectively.

In this work, we fabricated 20-100 nm thick Ga-hyperdoped Ge layers by surface modification of Ge substrates using a combination of GeGa deposition and PLM. The Ga-hyperdoped Ge layers have a nominal Ga concentration of 5 at.% and, in one sample, a measured Tc of up to ~0.86 K. We note that this value for Tc is the highest ever reported in the literature for germanium-based superconductivity. Here, we present detailed characterization results of the samples performed by XTEM, SIMS, RBS-C, Raman, and electrical and magneto-transport properties measurements from mK to 300 K.

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