NanoWestern

Western Science

Issue 1 2024

Optical Properties of SiGeSn Alloys Fabricated by Ion Implantation

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The integration of electronics and photonics systems has led to significant advancements in technology. This convergence has resulted in devices that exhibit improved characteristics such as reduced size, increased processing speed, lower power consumption, and cost-effectiveness, among other benefits. In parallel with the growing research in silicon (Si) photonics, new materials are continuously being developed and modified to meet specific requirements and to further drive technological progress. One key strategy to address challenges associated with silicon's optical properties is alloying. Group IV alloy materials have emerged as a promising frontier in this field, offering several advantages, including compatibility with complementary metal-oxide-semiconductor (CMOS) technology, a low bandgap, and high carrier mobility,

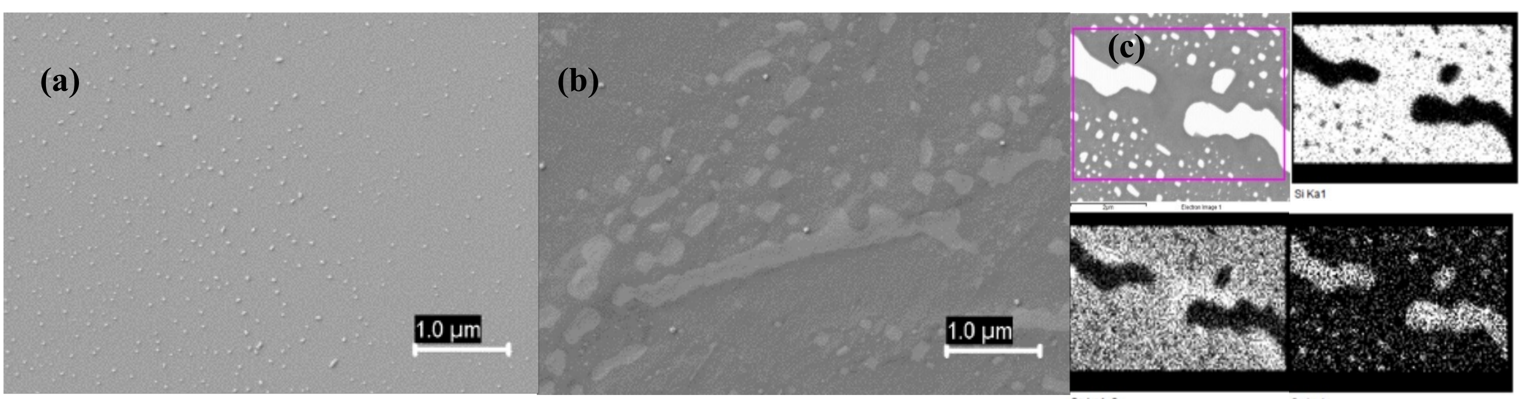

Fig. 1: SEM results for SiGeSn (a) as is, (b) 600^{o}C, showing onset of segregation at high annealing temperature (c) EDX for the 600^{o}C sample.

among other attributes. While the significance of alloying in advancing material science is evident, a fundamental challenge persists: achieving the ideal alloy compositions for the desired short-wavelength (SWIR) technologies in optoelectronics applications.

In this research project, $Si_xGe_{1-x-y}Sn_y$ alloys were fabricated by ion implantation followed by thermal annealing in a furnace (N_2, 30mins, 0 – 800^{o}C). The challenge which we addressed was identifying an optimal annealing condition for creating alloys with the higher atomic fraction of Sn incorporated into SiGe lattice. Our primary objective was to overcome the growth challenges, particularly those related to the successful incorporation of Sn into the alloy. Compositional and structural characterization was conducted utilizing Rutherford Backscattering Spectroscopy (RBS) at the Western Tandetron Accelerator Facility and Scanning Electron Microscopy (SEM) at the Western Nanofabrication Facility. These techniques enabled us to gain insights into achievable alloy compositions (with substitutionality details) and the optimal annealing temperature to prevent segregation onset, particularly for Sn (Fig. 1), which has a low solid solubility in Si and Ge (<1%). We also applied FIB/EDX to explore formation of Sn clusters in the range of Ge and Sn implantation (Fig.2).

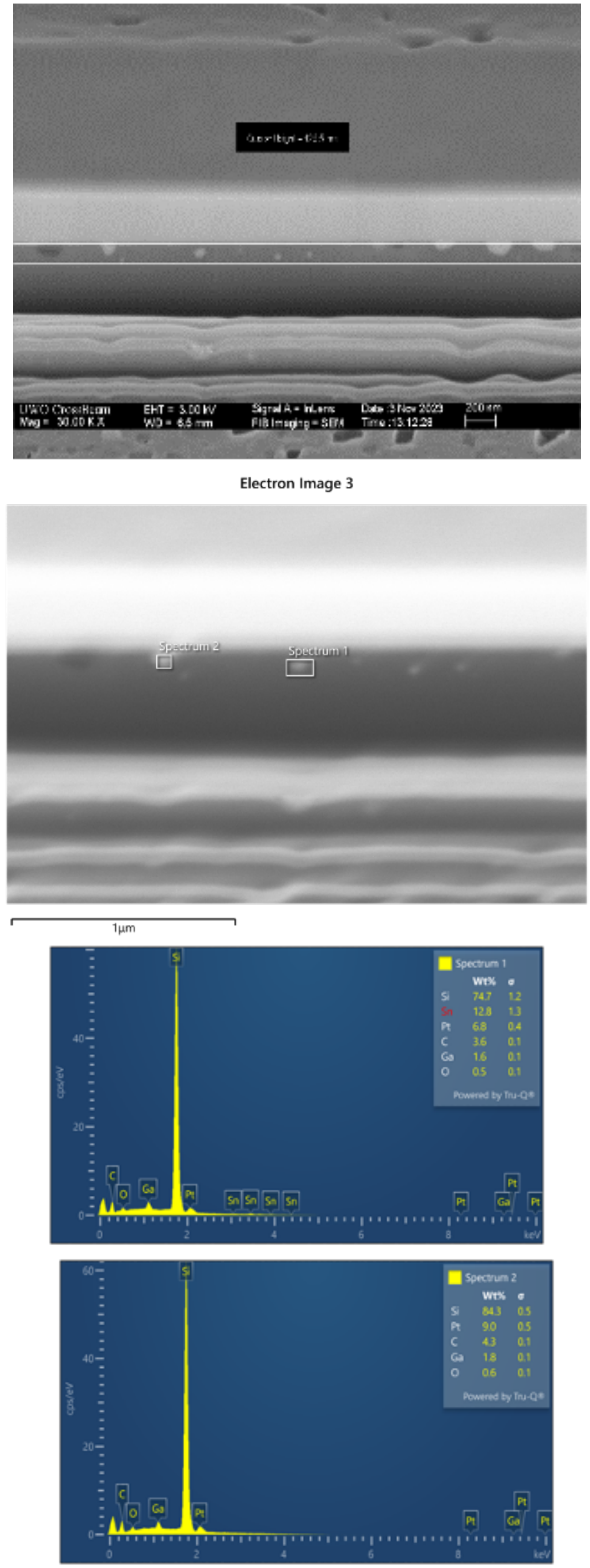

Fig. 2: FIB/EDX results for SiSn annealed at 800^{o}C, showing Sn precipitates through the implanted profile (~130 nm).

We studied the optical properties of our samples using Spectroscopic Ellipsometry (SE), which was performed at the Western Nanofabrication Facility. This analysis allowed us to assess the impact of alloying and varying annealing temperatures on the optical properties of the materials. The SE results demonstrated that our approach resulted in a substantial enhancement of the optical properties, particularly in terms of light absorption coefficient, compared to pure Si (Figure 3).

In conclusion, the combination of ion implantation and subsequent thermal annealing emerges as a promising approach to address the challenges associated with the growth of group IV alloys. By carefully optimizing the alloy composition and annealing temperature, we can achieve $Si_xGe_{1-x-y}Sn_y$ alloys with enhanced optical properties tailored for short-wavelength infrared (SWIR) optoelectronic applications, surpassing the capabilities of pure silicon (Si).

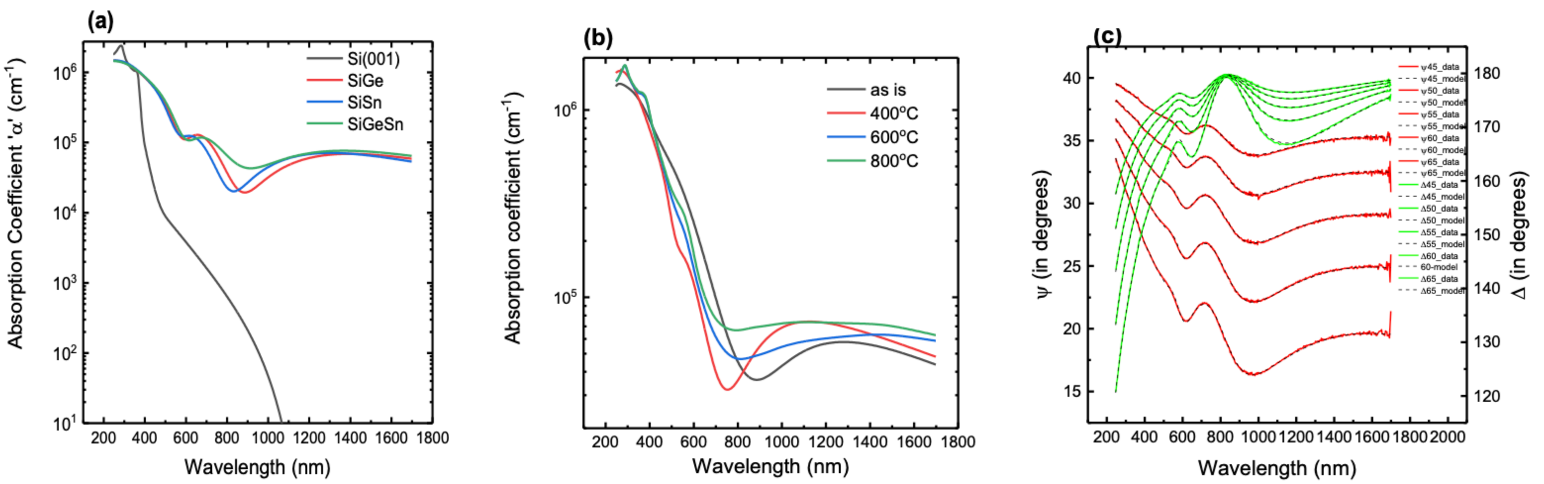

Fig. 3: Absorption coefficient, α, as a function of wavelength measured for (a) Si, SiGe, SiSn, and SiGeSn samples annealed at 400°C (b) SiGeSn samples annealed at different temperatures, (c) Typical SE raw data fitting model (MSE = 2.13).

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