Seminar

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Institute for Plasma Research

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Title: Depth resolved defects dynamics and recovery on ion-implanted 6H- and 4H- SiC: Insights from Raman, Luminescence and Positron Annihilation studies

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Abstract

This study is focused on defect analysis for two different energy range of irradiations, high (~100-500 keV) and low energy (< 1000 eV) on SiC and Si surface respectively. This talk is dedicated on defects in Silicon Carbide (SiC) which is critically influence its electrical, optical, and mechanical behaviour. They can trap free carriers—limiting mobility—but also enable advanced functionalities such as qubits for quantum computing, cryptography, and single-photon emission (SPE). Hence, understanding their creation, distribution, and evolution is essential. The present talk emphasizes Positron annihilation-variable energy positron beam coupled with Doppler broadening spectroscopy, Raman and Luminescence signatures for the defect's studies precisely. Silicon carbide, a wide band gap semiconductor, is known for high electron drift velocity, excellent carrier mobility, and superior thermal and chemical stability, making it ideal for high-power, high-temperature, and high-frequency devices. It also serves as a GaN-based blue LEDs, a host for quantum SPE and apart from electronics, in the ITER fusion program, SiC and its composites are strong contenders for plasma-facing first-wall and cladding applications due to their low neutron activation, radiation hardness, and high-temperature endurance.

To enhance SiC functionality for semiconductor applications, doping with N^+ and/or Al^+ is essential to form n- and/or p-type regions. However, conventional thermal diffusion is limited by SiC's hardness, low solubility, and limited diffusion co-efficient, multilayer formation making dopant control challenging. Ion implantation provides superior precision in dopant depth and concentration, enabling fabrication of p–n and p–i–n multilayer structures. However, implantation introduces lattice defects—vacancies, antistites, and complexes—through nuclear and electronic energy loss processes, leading to amorphization. Controlling and characterizing these defects is vital for achieving full dopant activation and desired device performance. In this study, semi-insulating 6H-SiC was implanted with N^+ (130 keV, 10^{15}–10^{16} ions/cm^2) and Al^+ (400 keV, 10^{14}–10^{16} ions/cm^2), while 4H-SiC was implanted with O^+ and N^+ (100–500 keV) to form n-, p-, and i-layers for advanced device and quantum applications. Post-implantation annealing at 800–1000 °C aided defect recovery and dopant activation. SRIM-2013 simulations provided ion range and displacement profiles consistent with experimental data.

Among various techniques, Variable Energy Positron Annihilation Doppler Broadening methods (PAS-DBS) proved most sensitive to vacancy-type defects. PAS revealed defect depths up to ~300 nm for N^+ and ~650 nm for Al^+ implantation. Increasing S-parameter with positron energy indicated mono-/divacancies at low fluence and vacancy clusters, voids at high fluence. VEPFIT fitting procedures showed multilayer defect profiles. Annealing markedly reduced open-volume defects, confirming recrystallization and dopant activation and defects migrations towards to surface. Raman spectroscopy revealed disorder and recovery via A_1(LO) phonon mode and z- scan analysis, consistent with PAS results, while photoluminescence

spectra (555–561 nm) exhibited deep level defect-related emissions and reactivated upon annealing, indicative of potential SPE behaviour.

This integrated study establishes clear correlations between implantation-induced defect evolution, recovery processes, and precise depth, type and migration of defects with annealing in SiC, which is technologically importance in device processing. The insights are crucial for defect-controlled device fabrication, dopant activation, optimization of quantum-active SiC development and contribution to radiation-tolerant materials research in ITER plasma–material initiatives.

References

1. **K. Kamalakkannan**, R. Rajaraman, K. Sivaji, Mukesh Ranjan, *Luminescence signature of deep level defects evaluation in N+ implanted semi-insulating 6H- SiC*, Materials Letters 404 (**2026**) 139616.
2. F. Linez, I. Makkonen, F. Tuomisto, *Calculation of positron annihilation characteristics of six main defects in 6H-SiC and the possibility to distinguish them experimentally*, Physical Review B, 94 (2016) 014103