



ID de Contribution: 91

Type: Poster

Carbon nanotube assemblies for the low-perturbation detection of diluted ion beams

We present the development of a novel detection system specifically engineered for the characterization and detection of diluted ion beams with fluxes below 10^3 particles/s and down to the single charged particle. Furthermore, the device is designed to provide sub-micrometer spatial resolution while ensuring minimal disturbance to the ion beam, a feature crucial for applications requiring precise control over single-ion delivery. Such a detector could enable deterministic ion implantation in a wide range of target materials [1], paving the way for the controlled creation of engineered defects with high spatial accuracy. These capabilities are particularly relevant for emerging fields such as quantum sensing and quantum information processing, where the spatial and charge precision of defect placement directly impacts device performance.

The detection platform is based on a forest of Multi-Walled Carbon Nanotubes (MWCNTs) [2], grown via Chemical Vapor Deposition (CVD). This nanostructured material serves a dual purpose: acting both as a physical guide for the ion beam and as an active medium for signal generation. A narrow channel, precisely milled into the nanotube forest using Focused Ion Beam (FIB) techniques with <10 nm resolution, defines the spatial resolution of the system and confines the ion beam. As the charged particles interact with the inner walls of the nanotube array, they induce electrical signals that can be measured for detection. Additionally, the beam's interaction with the dense MWCNT network leads to the emission of secondary electrons, which contributes to signal amplification and enhances overall sensitivity and robustness.

The detector's behavior and performance are assessed through a combination of numerical simulations and experimental validation. Finite Element Method (FEM) simulations and Monte Carlo-based tools, such as Geant4 [3], are used to model the electric field distribution and particle interactions within the device. Experimentally, the high-resolution structuring of the MWCNT forest is complemented by advanced micro- and nanolithography processes, enabling the fabrication of various detector architectures and channel geometries. This comprehensive approach supports the optimization of detector design for future integration into ion beam systems used in quantum technologies.

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3. Q. Gibaru et al., Geant4 physics processes for microdosimetry and secondary electron emission simulation: Extension of MicroElec to very low energies and 11 materials (C, Al, Si, Ti, Ni, Cu, Ge, Ag, W, Kapton and SiO₂), NIM B: Beam Interactions with Materials and Atoms 487, 66 (2021), ISSN 0168-583X. <https://doi.org/10.1016/j.nimb.2020.11.016>.

Title

Carbon nanotube assemblies for the low-perturbation detection of diluted ion beams

Topic

Solid state sensors

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Classification de Session: Poster session - Cocktail