Deterministic Ion Implantation for Quantum Materials

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Focused ion beam implantation systems are ideal tools for solid state engineering of quantum materials. Systems with high spatial resolution and isotopic selectivity [1] have been able to implant large arrays of dopants in wide bandgap materials which have been locally annealed to form site-selective single photon emitters [2]. Single ion implantation for qubit generation requires deterministic detection with high efficiency. While this has been previously approached using Ion Beam Induced Charge (IBIC) detection [3], this imposes specific design considerations including gate oxides and electrodes specific to the detection mechanism as opposed to the end-device. An alternative method which circumvents the requirement for electrodes on the substrate itself is the detection of secondary electrons emitted from a surface due to ion implantation. The detection efficiencies for this method are substrate dependent and vary with ion energy [4]. Understanding the mechanisms leading to the variation in detection efficiencies across substrates may reveal pathways for surface functionalisation, improving detection efficiencies in substrates which do not require the dedicated electrode architecture needed for IBIC detectors.

References

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[2] Cheng, X., Thurn, A., Chen, G., et al., arXiv preprint (2024) arXiv:2409.07421
[3] Jakob, A., Robson, S., Schmitt, V. Advanced Materials 34 (2022) 2103235
[4] Cassidy, N., Blenkinsopp, P., Brown, I., et al., Phys. Status Solidi A, 218 (2021) 2000237

Figures

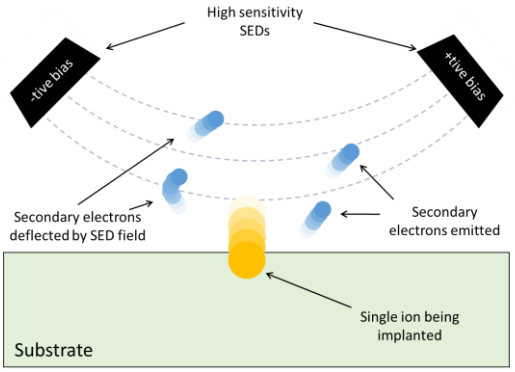

Figure 1: Schematic of the deterministic single ion implantation process. Secondary electrons emitted from the substrate surface due to ion implantation are collected by a high sensitivity secondary electron detector (SED). The correlation between detected events and expected distribution enables the calculation of the detection efficiency for an ion-substrate combination.

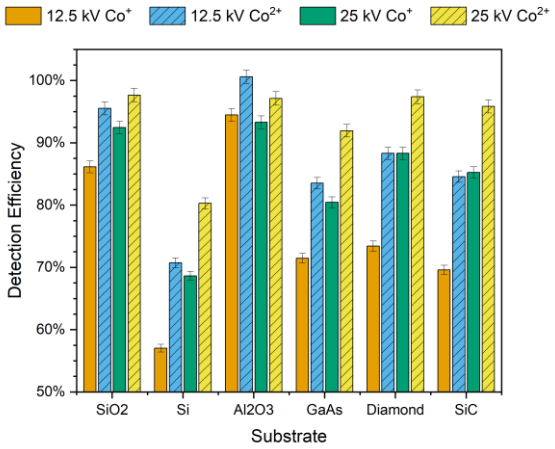

Figure 2: Detection efficiencies of Co ions into various substrates. 25 keV beams (blue hatched, doubly-charged 12.5 kV, and green, singly-charged 25 kV) have similar efficiencies for some substrates but vary significantly for others, indicating the importance of ion charge in increasing detection efficiency for a given substate.