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Atomic-scale materials characterisation with radioactive isotopes - highlights from emission Mössbauer spectroscopy

Intentionally incorporating foreign atoms in semiconductors to realise new and/or novel functionalities gives rise to structural changes that profoundly affect their electronic, magnetic and optical properties. Consequently, information on material properties and dynamic processes such as dopant diffusion and relaxation processes are necessary and can be determined using various techniques. A particular class are techniques employing radioactive isotopes implanted in materials as probes. These combine a two-fold approach: (a) material modification and (b) material characterisation at the atomic level, the latter achieved through utilising the isotopes mainly as "spies" via the radiation/particles emitted during decay. This provides knowledge on lattice sites of desired daughter dopants, lattice location changes with thermal annealing, and the defects/complexes formed with host atoms.

Mössbauer Spectroscopy is a very sensitive technique capable of detecting minor shifts in energy levels that emanate from hyperfine interactions between the nuclear moments of the probe/dopant and any local electric and magnetic fields in their immediate environment. A novel extension is emission Mössbauer Spectroscopy (eMS) employing short-lived radioactive isotopes developed at ISOLDE, CERN. eMS studies have been undertaken mainly using ^{57}Mn* ($t_{1/2}$ = 1.5 min) produced via proton-induced fission in a UC_2 target followed by multistage laser ionisation [1], mass separation and acceleration to 40-60 keV. In addition, other precursor isotopes, such as ^{57}Co ($t_{1/2}$= 272 days) and ^{119}In ($t_{1/2}$= 2.4 min), have also been used.

Over the years, eMS has been applied in several different material systems at ISOLDE, with investigations initially on the role of Fe in silicon to recent studies on the nature and origin of magnetic effects observed in transition metal doped semiconductors[2-5] envisaged for spintronic applications. Special features of the technique will be presented and discussed, together with representative results in binary[4] and ternary III-nitrides[5]. The results will mainly focus on investigations of the lattice sites of the probes, their charge and spin states, and the magnetic interactions of dopants in ternary-nitrides (virgin and Mn pre-doped).

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[4] Masenda et al. J. Magn. Magn. Mater. **401** (2016)1130.
[5] Masenda et al. New J. Phys. **24** (2022) 103007.

Notes

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