Applicability of Femtosecond Laser Accelerated Ions in Perturbed Angular Distribution Studies

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Abstract

The perturbed angular distribution (PAD) technique is based on the interaction of nuclear electromagnetic moments of a probe nucleus implanted into a solid with the hyperfine fields arising from the electronic charge and spin distributions in the vicinity of the probe. The interaction produces oscillations in the time-decaying intensity of γ-rays emitted by the probe, which in turn yield microscopic insight into the electronic and magnetic behaviours of the solid. In a typical accelerator based time-differential PAD experiment, pulsed ion beams of ~ *ns* beam pulse width (BPW) are bombarded on a thin target to produce probe nuclei of suitable nuclear *g*-factor g_N and several tens of *ns* of lifetime $\tau_{1/2}$ in a nuclear fusion evaporation reaction, which subsequently are recoil implanted in the solid under study and decay by γ-ray emission.

The recent advent of *fs* laser accelerated ion beams, which have energies sufficient to produce such nuclear reactions, opens up a possibility to exploit these ions for PAD measurements with the following two distinct advantages over the conventional accelerator-based technique. **(i) Simultaneous production of multiple ion beams** (e.g., H^+ and C^{n+}): This feature has the possibility to generate multiple probes simultaneously, e.g., in reactions ^{45}Sc (^{1}H) ^{45}Ti*, ^{45}Sc (^{1}H, p) ^{45}Sc, ^{45}Sc (^{12}C, p2n) ^{54}Fe* and ^{45}Sc (^{12}C, αp) ^{52}Cr* when the two ions bombard a ^{45}Sc target; here, the γ emitting probes are marked with a star. When implanted into a compound/heterostructure containing the same elements, these probes would predominantly substitute the corresponding lattice sites, enabling one to study local electronic and magnetic properties at these different sites in single experiment. However, for the γ-rays to be utilizable, the BPW must be shorter than the $g_N\tau_{1/2}$ value for the corresponding probe state. Therefore, with accelerator beams of BPW's several *ns*, it is not possible to study γ-rays from, for example, ^{45}Ti* and ^{52}Cr* having $g_N\tau_{1/2}$ values 1.2 *ns* and 6.2 *ns*, respectively. This can, however, be achieved with the laser accelerated beams with **(ii) controllable BPW**. As an example, the BPW can be made any small fraction of *ns* just by utilizing the central high-energy part of the divergent beam when passed through a suitable hole with laser-target-to-PAD-target distance of about 10 *cm*. Currents produced even with these energy-filtered beams can be comparable with those delivered by conventional accelerators, and hence are suitable to do PAD experiments. With sub-nanosecond BPW's, the oscillations in the *γ*-ray intensities from probes with $g_N\tau_{1/2}$ as low as 5 *ns*, like ^{52}Cr*, can be well resolved when the probe is located inside a magnetic material having several tens of Tesla of hyperfine fields. Further, in an external field of presently achievable pulsed 60 – 70 T fields, it is also feasible to study γ-rays from probes like ^{45}Ti* with $g_N\tau_{1/2}$ ~ 1 *ns*.