Laser techniques for a new class of scintillators

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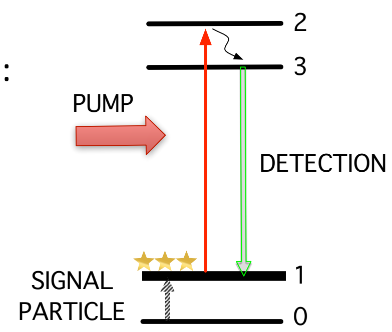
Introduction

Our ideas point to the development of a new generation of radiation detectors exploiting the rich collection of optical processes in laser spectroscopy, in line with the flourishing trend of interdisciplinary application of specific techniques to branches of Physics other than the ones in which they are widespread. Through modification, new functions are found in a different branch, where ways to overcome inherent limitations in its traditional instruments are finally found.

The Idea/Concept

We select three possible mechanisms to be applied in the field of radiation detection:

1. rare-earth (RE) upconversion
2. via phonon upconversion
3. laser oscillation/amplification



In upconversion, low energy incident radiation (e.g. infrared light) is converted into higher energy emitted radiation (e.g. visible light). It is efficiently accomplished by incorporating rare-earth ions in inorganic matrices. In fact, the f-electron configurations of these ions, a three- or five-level energy cycle can be identified, in which energy is first absorbed by the ground level (0) to reach a metastable intermediate state (1), characterised by relatively long lifetimes (~ms). Subsequently, another excitation photon delivered by a pump laser tuned to the transition from level 1 to 2 promotes the ion to the state (2). A radiative transition from this latter excited state back to the ground state or some other lower- energy state, results in a higher energy photon emission. To date, this mechanism has been extensively applied for the development of lasers and optical devices, but it has not yet been applied to particle detection. In the envisaged detector, the active material is transparent to the pump radiation, until a particle excites low energy levels (hundreds to tens of meV) and triggers a fluorescence signal from a higher level, to be detected with conventional detectors.

A particle interaction in a material gives rise to phonons as well. Through a careful selection of the active material, the generated phonon energy can be converted to a photon via another photon, delivered by the pump laser, whose energy is smaller than that required for the selected transition. This idea follows the well known mechanism of laser cooling of solids (or optical refrigeration), an anti-Stokes process that has been demonstrated to allow cooling of solid state materials from room temperature through a net temperature drop of 190 K.

Finally, another key photonic process we envisage as applicable to the field of radiation detection is the coherent amplification of photons. An OPO (optical parametric oscillator), a wave-mixing nonlinear device, might for example be approached as a particle detector, provided the nonlinear material in which wavelength conversion takes place is also a good scintillator. The particle interaction would trigger a coherent emission if the OPO cavity is operated just below threshold.

Potential Impact

The great potential of these new, all-optical detection approaches lies in the possibility to lower the energy threshold in relatively large detector volumes, opening a window in experiments devoted to the search of particles that interact with matter only very weakly.

As sensors of ionizing radiation fields, in the shape of small RE-doped optical fibers, they might well be employed in medical dosimetry, to monitor remotely a real time dose radiation field with punctual evaluation.