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Recent developments of ion beam induced luminescence: radiation hardness study of thin film plastic scintillators

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Abstract

Ion beam induced luminescence (IBIL) measurements have been performed on thin film scintillators based on polyvinyltoluene (PVT) and 6FDA-DAD and BPDA-3F polyimides with H^+ (1.85 MeV) and He^+ (1.8–2.2 MeV) ion beams. The radiation hardness of the undoped polymers has been verified to depend mainly on the deposited energy density, polyimides exhibiting a higher resistance with respect to PVT. In PVT a new fluorescence band, attributed to the radical precursors of the network crosslinking, has been observed. The efficiency of doped polymers degradates with a higher rate, depending on the dye intrinsic lability. At high radiation fluences, the relative efficiency to NE102 of doped polyimides scintillators increases owing to the intrinsic host improved resistance.

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1. Introduction

It is well known that the impact of energetic ions on solid samples induces the emission of visible light luminescence owing to the electronic excitation of emitting centres or to the radiative de-excitation of the defects formed into the matrix during the irradiation. The shape and the evolution with the fluence of the luminescence features depend on several parameters, such as the type and the energy of the impinging ion, the chemical environment of the emitting impurities, the defects and the radiation hardness of the material. Ion

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beam induced luminescence (IBIL) has been exploited for studying the ion–matter interaction process [1,2] and for analysing several types of materials, namely inorganic materials for scintillators [3], ceramics [4,5], diamond [6,7], geological samples [8], biological samples [9], thin molecular films [10]. In spite of this great amount of applications, until now few studies have been performed on the evolution under ion irradiation of the fluorescence bands of organic materials [10,11], or plastic scintillators [12].

Plastic scintillators exhibit fast time response, low cost and easy processability in different shapes and dimensions. For these reasons, they have been widely used in multidisciplinary radiation experiments and applications [13,14], namely in radiation beams dosimeters and in PHOSWICH detectors for the simultaneous counting of different radiations [15]. On the other hand, the low radiation resistance of organic materials leads to a degradation of scintillation intensity and energy resolution during the irradiation, owing both to the damage of the fluorescent chromophore groups and to the formation of quenching centres. Among the most radiation resistant polymers, aromatic polyimides are a class of high-performance polymers, with an improved radiation hardness owing to the presence of aromatic rings along the polymer chain, strong imide bonds and charge transfer complexes between adjacent chains. Recently, systems constituted by fluorinated polyimides doped with dye molecules has been obtained with the aim to produce high radiation resistance plastic scintillators [16,17].

In this work, IBIL analysis is performed both on new scintillating systems constituted by aromatic polyimide (PI) hosts doped with and on a traditional polyvinyltoluene (PVT) based scintillator. The radiation hardness of PVT and aromatic polyimides was measured from the degradation of the intrinsic fluorescence bands under irradiation with MeV light ions. The same measurements were performed on the corresponding scintillator systems: NE102 (BC400 from Bicron), which is constituted by a PVT matrix containing p-terphenyl (PTP) and 2,2′-*p*-phenylenebis[5-phenyoxazole] (POPOP) dyes, and Nile-Red (NR) doped polyimides (PIs). The polyimides were 4,4′-hexafluoroisopropylidene diphthalic anhydride-2,3,5,6-tetramethyl paraphenylene diamine (6FDA-DAD) and 3,3′,4,4′-biphenyltetracarboxylic acid dianhydride-1,1-bis(4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane (BPDA-3F). These polymers were chosen with the aim to optimize both the transparency and the radiation hardness of the matrix. In order to obtain a plastic scintillator from PI hosts, a dye, whose absorption spectrum overlaps with the polymer fluorescence band, was dispersed into the matrix. By this way, the dye collects the radiation induced electronic excitation energy by means of an energy transfer mechanism [18] and gives rise to the light emission. For 6FDA-DAD and BPDA-3F, whose emission bands lie at 500 and 520 nm, respectively, the NR dye was chosen for its high quantum efficiency and for its absorption band position, which lies at about 520 nm when dispersed in polyimide hosts.

2. Experimental

PI films were synthesized following a standard chemical imidization procedure [19], which was preferred with respect to the thermal imidization route since at the curing temperature the thermal degradation of the dispersed dye can occur [20]. The dye amount in the solid polymer was 1 wt%. PVT and NE102 bulk materials (Bicron) were dissolved in toluene. Both PI and PVT films were obtained from the resins by spin coating on silica or silicon substrates and by vacuum drying. The thickness of the deposited films ranged from 0.35 to 3.5 μm, as measured with a Talystep, depending on the resin density and on the deposition parameters.

IBIL measurements were performed by irradiating the samples at the Van de Graaf accelerator AN2000 of the INFN Laboratori Nazionali di Legnaro with H^+ (1.85 MeV) and $^4He^+$ (1.8–2.2 MeV). The beam current was kept to a density of about 10 nA/mm^2 in order to minimize the heating effects. In Fig. 1 the experimental apparatus for IBIL measurements is sketched. The light emitted from the film was collected during the irradiation by four silica lenses and focussed on a silica fibre bundle. The fluorescence spectrum