Ion Beam Induced Luminescence (IBIL) for scintillator analysis

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Ion Beam Induced Luminescence (IBIL)

Radiation Induced Luminescence (RIL)

Ionoluminescence (IL)

Spectral analysis of the UV-Visible light emission from a solid target induced by ion irradiation.
IBIL principles

Ion track

δ-rays

Luminescence processes
Inorganic Solids

- Excitation
- Intraband transition
- Intrinsic Defects
  - Intrinsic Luminescence
- Conduction Band
- Impurities
  - Extrinsic Luminescence

Valence Band
In organic solids the luminescence follows the excitation of delocalized electrons in unsaturated carbon bonds (chromophores).
Applications of IBIL

- IBIL for material analysis

Ions release more energy than electrons and can create a higher density of electronic excited states.
Qualitative and quantitative analysis of transition elements in geological samples

Concentration quenching of Er\(^{3+}\) in Lithium deficient Li\(\text{NbO}_3\)

Fig. 1. Typical IL spectra of apatite (top) and calcite (bottom). In calcite spectrum the dominant peak corresponds to manganese (Mn\(^{2+}\)) activated luminescence at 6200 Å.

Fig. 3. Comparison of Er\(^{3+}\) line emission from Er doped stoichiometric and congruent lithium niobate. 900 keV H\(^+\) ions at 0.5 μA cm\(^{-2}\).
μbeam mapping of diamond structural defects

Mn$^{2+}$ profiles in ancient human bone

Fig. 4. The monochromatic map taken at 415 nm shows microprobe scan damage on the interface between undamaged and partially damaged natural diamond. The scan damage is over a region 100 μm x 100 μm size.

Fig. 3. 3D-plot of the IL spectra observed from the ancient bone sample.
Applications of IBIL

- Study of ion-solid interaction mechanisms

**Creation-aggregation mechanisms of ion induced defects in silica**

**Ion-irradiation annealing of Tb implanted Al₂O₃**
IBIL measurement set-up

- H⁺ 1.85 MeV
- He⁺ 1.8-2.2 MeV
- 10 nA/mm²
- 2x10¹² ions/cm² per spectrum

Diagram showing the IBIL measurement set-up with various components:
- Sample
- Chamber
- Beam
- Light
- Focalizing system
- X-Y-Z stage
- Fiber bundle
- Spectrometer
- CCD
- PC
Organic scintillators

- Study of the evolution of the luminescence of organic scintillators under ion beam irradiation

- Study of new organic scintillators based on more resistant polymers

(G V Experiment - ASTHICO)
Organic scintillators

Incident radiation

Electronic excitation

Polymer chromophores

Energy transfer

Dye

Light
Then energy transfer process is promoted if the emission spectrum of the host overlaps with the absorption spectrum of the sensitizing dye.
PVT based scintillators (NE102) are constituted by a PVT matrix with two dyes for the energy transfer and the wavelength-shifting.

**PVT matrix**

- **POPOP** ($p$-bis[2-(5-phenyloxazolyl)]benzene)
- **PTP** (para-terphenyl)

**Wavelengths:**
- 330 nm
- 360 nm
- 430 nm
Polyimide based scintillators

Polyimides are constituted by two structural units (monomers):

\[
\begin{align*}
\text{n} & \quad \left\{ \begin{array}{c}
\text{O} \\
\text{C} \\
\text{C} \\
\end{array} \right\} \\
\text{+ n} & \quad \left\{ \begin{array}{c}
\text{H}_2\text{N} \\
\text{O} \\
\text{O} \\
\text{NH}_2 \\
\end{array} \right\}
\end{align*}
\]

Polyimides are radiation resistant polymers owing to their aromatic and imide groups:

\[
\begin{align*}
\frac{-2n \text{H}_2\text{O}}{\Delta} & \quad \left\{ \begin{array}{c}
\text{O} \\
\text{C} \\
\text{C} \\
\text{N} \\
\end{array} \right\}_n \\
\end{align*}
\]

Transparent and resistant polyimides were synthesized by means of a room temperature chemical imidization route with the aim to disperse fluorescent dyes into the matrix.

Film Thickness

0.35-3.5 μm
Polyimide based scintillators

6FDA/3,3'-DDS

BPDA/3F

NILE RED

Normalized Intensity vs. Wavelength (nm)

Polyimide Emission
Nile-Red Absorption
Nile-Red Emission
Ion irradiation induces the desorption of gaseous species and the rupture of chromophore groups.
The degradation of the fluorescence bands is observed at the fluence increase.
IBIL study of PVT

The higher wavelength band is attributed to the radical precursors of the polymer crosslinking.
The PVT radiation hardness was measured from the degradation of the intrinsic band. The higher wavelength band evolves in a different manner as a function of the fluence, depending on the ion.
$$\rho = \left( \frac{dE}{dx} \right) \times \Phi \text{ eV nm}^{-3}$$

The degradation of the intrinsic band depends on the deposited energy density.

The new band increases with the radical concentration, and decreases when the radicals aggregate to form an a-C:H structure.

The new band intensity depends on the deposited energy density too, reaching the maximum at about 60 eV/nm$^3$. 
IBIL study of polyimides

IBIL spectra of polyimides present the same bands of UV-Vis fluorescence spectra.

Polyimides exhibit higher radiation hardness with respect to PVT.

The degradation rate depends on the deposited energy density for polyimides too.
Scintillator spectral analysis

IBIL spectra of NE102 shown both the dye bands and the new radical band are observed.
The fluorescence degradation rate of dyes in PVT is higher than undoped PVT.

The fluorescence degradation of doped polyimides is higher than undoped polyimides and comparable to PVT dyes.
The fluorescence degradation of doped polyimides depends on the dye intrinsic lability.

This result is in contrast with what has been observed in literature with lower LET radiations (γ rays), where the scintillator resistance depends mainly on the polymer host.
Relative damage resistance

\[ E_{1/2} = \frac{dE}{dx} \times \Phi_{1/2} \]

Fluence (10^{13} \text{ ions/cm}^2)
<table>
<thead>
<tr>
<th>Compound</th>
<th>Incident ion</th>
<th>Energy Loss (eV/nm/ion)</th>
<th>$\Phi_{1/2}$ ($10^{13}$ ions/cm²)</th>
<th>$E_{1/2}$ (eV/nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVT (Intrinsic Band)</td>
<td>H⁺ (1.85 MeV)</td>
<td>18.5</td>
<td>5.8</td>
<td>11</td>
</tr>
<tr>
<td>PVT (Intrinsic Band)</td>
<td>He⁺ (1.8 MeV)</td>
<td>206</td>
<td>0.53</td>
<td>11</td>
</tr>
<tr>
<td>6FDA-DAD</td>
<td>H⁺ (1.85 MeV)</td>
<td>22</td>
<td>23</td>
<td>51</td>
</tr>
<tr>
<td>6FDA-DAD</td>
<td>He⁺ (1.8 MeV)</td>
<td>231</td>
<td>1.9</td>
<td>44</td>
</tr>
<tr>
<td>BPDA-3F</td>
<td>He⁺ (1.8 MeV)</td>
<td>231</td>
<td>5</td>
<td>115</td>
</tr>
<tr>
<td>NE102 (PT+POPOP)</td>
<td>He⁺ (2.2 MeV)</td>
<td>180</td>
<td>0.21</td>
<td>3.8</td>
</tr>
<tr>
<td>6FDA-DAD + NR</td>
<td>He⁺ (2.2 MeV)</td>
<td>203</td>
<td>0.4</td>
<td>8</td>
</tr>
<tr>
<td>BPDA-3F + NR</td>
<td>He⁺ (2.2 MeV)</td>
<td>203</td>
<td>0.3</td>
<td>6</td>
</tr>
</tbody>
</table>
IBIL for the study of scintillators

- Comparison of the optical spectrum among different scintillators
- Dependence of the optical spectrum on the nucleus species and energy
- Selection of the spectral contributions to the scintillation lifetimes
- Relative efficiency measurements
- Homogeneity tests
Perspectives for the study of CsI:Tl scintillators

- Dependence of the spectral properties on Tl concentration (light yield, spectrum shape).
- Dependence of the spectral properties on the fabrication procedures.
- Study of the spectral properties with different nucleus and energies.