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Color center creation in LiF crystals irradiated with 5- and 10-MeV Au ions

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Abstract

The peculiarities of defect creation in LiF crystals by irradiation with 5- and 10-MeV Au ions have been studied using optical spectroscopy. The crystals were irradiated at room temperature with fluences from 1×10^{12} to 2×10^{14} ions/cm^2 at various beam current densities (1–200 nA/cm^2). The short ion range in LiF allowed measurements for higher absorbed energy densities and high defect volume concentration. The efficiency of single F center and F_n and larger aggregate creation depends drastically both on ion fluence and flux (beam current). Color center creation is less effective for 5-MeV Au ions than for 10-MeV Au ions, which produce δ electrons with energies sufficient for creation of cation excitons (∼62 eV). The peculiarities of color center accumulation in LiF crystals under MeV Au ion irradiation are considered taking into account the nonlinear kinetics of interstitials (H centers).

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1. 1.Introduction

In alkali halides and some other ionic crystals, the exciton mechanism of defect creation is much more efficient than elastic collisions [1–4]. This was also demonstrated for the irradiation with fast heavy ions of the energy between several hundreds MeV and GeV [5–7]. In this study we used Au ions with a lower energy of 5- and 10-MeV. The irradiation parameters at much lower energy in comparison with GeV ions are presented in Table 1. The maximum energy of the δ electrons is only 55–110 eV and thus much lowers than for GeV Au ions. Moreover, the energy of δ electrons is close to the energy of the anion (13.5 eV) and cation (∼ 62 eV) excitons responsible for defect creation by the exciton mechanism [9–10]. The mean nuclear energy loss (elastic collisions, S_n) for 5-MeV Au ions is larger than the mean electronic energy loss (S_e) and for 10-MeV ions $S_n \approx S_e$ (Table 1). Therefore, elastic collisions can influence the defect creation. However, at present it is not clear how to distinguish the defect creation by elastic collisions from the efficient exciton mechanism.

The defect creation peculiarities in LiF crystals under irradiation with 5- and 10-MeV Au ions are investigated as a function of fluence and flux using optical spectroscopy. The fluence was varied from 10^{12} to 2×10^{14} ions/cm^2 with different beam current density (ion flux) in a wide range from 1 to 200 nA/cm^2. Due to their small range (Table 1) rather high defect concentration can be investigated without reaching the optical density limit.

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Table 1
Irradiation parameters of Au in LiF crystals according to SRIM 2006 [6,8]

Ion energy, E_{ion}, MeV	Range R, μm	Mean energy loss, S, keV/nm		Maximal energy of δ electrons, eV
		Electronic, S_{elec}	Nuclear, S_{nuc}	
5	1.14	1.7	2.6	55
10	2.34	2.1	2.0	110
2187	92.0	23.8	0.02	24×10^3

2. Experimental

All experiments were performed on pure LiF single crystals grown from the melt in an inert atmosphere (Korth Kristalle, Germany). Thin platelets were cleaved from a crystal block along the (1 0 0) plane. The crystals were irradiated at room temperature (RT) perpendicular to the (1 0 0) plane with 5-MeV Au^{+2} and 10-MeV Au^{+4} ions at the Tandetron 3 MV accelerator of the Federal University of Rio Grande de Sulin Porto Alegre. The ion fluences (Φ) ranged from 1×10^{12} to 2×10^{14} ions/cm^2 and the beam current density was varied from 1 to 200 nA/cm^2. Taking into account the charge state of the ions (k), the flux φ amounted to:

$$\varphi \ [\text{ions cm}^{-2}\ \text{s}^{-1}] = 6.24 \times 10^9 \times i[\text{nA/cm}^2] \times k^{-1}, \quad (1)$$

where i is the ion beam current density (measured with an accuracy ± 0.1 nA/cm^2). To compare MeV and GeV ion irradiation, LiF samples were also irradiated at the UNILAC linear accelerator of GSI Darmstadt with 2187-MeV Au ions at a fluence of $\Phi = 4 \times 10^{10}$ ions/cm^2 with a flux $\varphi \sim 10^8$ ions cm^{-2} s^{-1} (the accuracy of Φ was about $\pm 20\%$; more details see in [6]). The range R of all ions was smaller than the thickness of the samples.

Optical absorption spectroscopy was performed at RT in a spectral region of 6.5–1.5 eV (190–850 nm) using a double-beam spectrometer ATI Unicam UV4. The most significant electron color centers are F and F_2 centers with absorption maxima at 4.95 eV (250 nm) and 2.79 eV (445 nm), respectively [6]. The complementary trihalide X_3^- hole centers (V_3), being stable at RT and having the absorption band in the VUV spectral region (maximum at 10.8 eV (114 nm)), were not investigated in this study [11].

The number of created F centers (n_F in cm^{-2}) in LiF was determined by the Smakula–Dexter formula [6–7]:

$$n_F = 9.48 \times 10^{15} \times D_F, \quad (2)$$

where D_F is the optical density at the absorption maximum of the F centers. The average volume concentration of the color centers N_F (cm^{-3}) can be estimated as $N_F = n_F/R$, where R is the ion range (Table 1).

3. Results

In Fig. 1, the absorption spectra of LiF irradiated with 5-MeV Au ions are compared with those of LiF irradiated with 2187-MeV Au ions. The optical density and the corresponding number of F centers for LiF irradiated at the low energy are several times lower than that for the high energy irradiation. In contrary, the absorbed energy density (E_{abs} [eV/cm^3] $= E_{ion} \times \Phi/R$) for 5-MeV ions is about two orders of magnitude higher than that for 2187-MeV Au ions. Note that for 5-MeV Au ions the concentration of aggregate centers in comparison with single F centers is much higher than for GeV Au ions. The reason is the difference in volume concentration of F centers, which is amounting to $N_F \approx 5 \times 10^{19}$ cm^{-3} for 5-MeV and $N_F \approx 4 \times 10^{18}$ cm^{-3} for 2187-MeV Au ions.

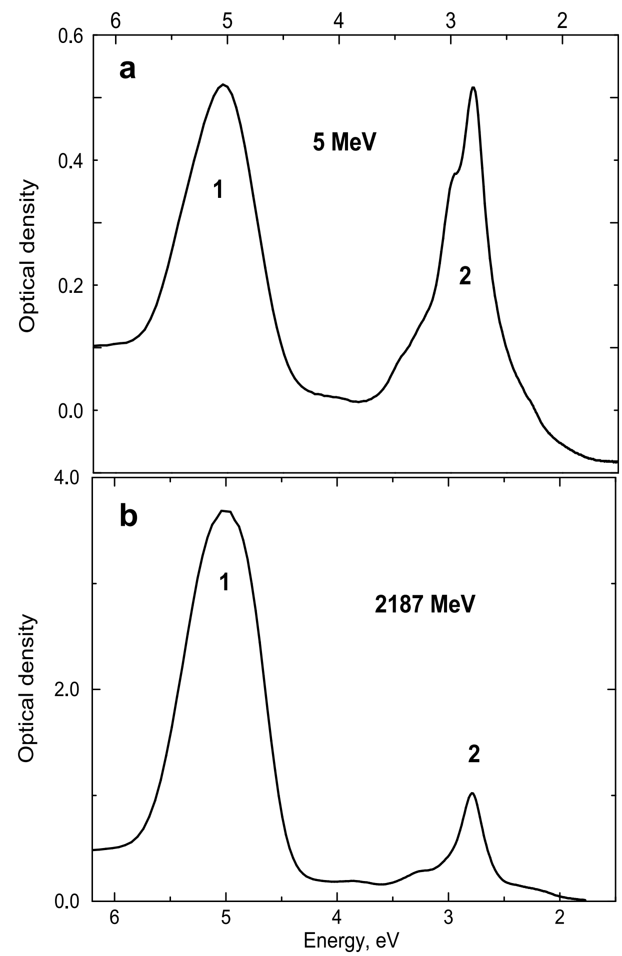

Fig. 1. Absorption spectra of LiF crystals irradiated with Au ions ((1) F center absorption peak, (2) absorption bands of F_n and aggregate centers): (a) 5-MeV at $\Phi = 5 \times 10^{13}$ ions/cm^2 ($E_{abs} = 2.2 \times 10^{24}$ eV/cm^3); $n_F = 4.36 \times 10^{15}$ ions/cm^2; (b) 2187-MeV at $\Phi = 4 \times 10^{10}$ ions/cm^2 ($E_{abs} = 9.5 \times 10^{21}$ eV/cm^3); $n_F = 3.17 \times 10^{16}$ ions/cm^2.