Ion-beam induced visible luminescence of Er_2O_3
酸化エルビウムの可視域イオンビーム誘起蛍光

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Ion-beam luminescence of sintered Er_2O_3 samples irradiated by Ar^+ ion-beams was measured in a visible range. Three luminescence bands observed at 640-690, 540-580, and 490-520 nm are due to intra-4f transitions of Er^{3+} ($4f^{11}$) in the sample. The clean Stark spectrum of the luminescence band at 640-690 nm suggests that the emitter Er^{3+} is situated in the C_2 cation sites of pure Er_2O_3. Each Stark component has the Lorentzian profile having a $\sim10^{12}$ Hz width in frequency. However, the resonance broadening accounts only 1 % of the total width.

1. Introduction

Er_2O_3 electric insulating coating is being developed for reduction of the MHD pressure drop in Li/V-alloy blanket systems [1]. It was demonstrated that the Er_2O_3 coating serves also as a tritium permeation barrier of blanket systems made of other breeder and coolant such as Flibe and Li-Pb [2]. However, neutron damages of the coating in fusion reactors are a big concern. Ion-beam damages are often used to simulate the neutron damages. Changes in crystallinity of the irradiated sample may be inferred from changes in ion-beam induced luminescence spectra, because optical transitions of trivalent Er ions (Er^{3+}) in the Er_2O_3 crystals are known rather strong and sharp [3]. The ground state of Er^{3+} has an incomplete 4f sub-shell ($4f^{11}$). The intra-4f transitions from lower excited states to the ground state are observed as the luminescence in Infrared and visible ranges. Tanaka et al. [4] investigated the ion-beam induced visible luminescence of Er_2O_3 coating samples irradiated by 100 keV H^+ and Ar^+ ion-beams at Osaka Univ. The similar measurements have recently been undertaken using an apparatus in NIFS in order to understand relations between the crystallinity and the luminescence spectra. In the present study, the visible luminescence spectra of sintered Er_2O_3 samples bombarded by Ar^+ ion-beams were measured.

2. Experimental apparatus

The experimental apparatus consists of an ion-beam source, a collision chamber, and a CCD spectrometer. The ion source is a part of medium current ion implanter (ULVAC IM-200MH-FB) used for semiconductor production (Freeman-type) in NIFS [5]. Ion-beam extracted from the Freeman ion source was introduced into the collision chamber after analyzing the mass to charge ratio by a magnet. We could use primary Ar^+ ion beam of about 0.1 ~ several μA in current at 33, 50, and 70 keV in kinetic energy. In the collision chamber, a movable stage made of stainless steels was installed to set the sintered Er_2O_3 sample disk (25 mmφ × 1 mm). To the ion-beam axis, the sample surface was leaned 45 degrees and placed (see Fig. 1). An electrode with a hole of 5 mm diameter was placed in front of the sample. The electrode surface was biased -100 V to retard secondary electrons from the irradiated sample. The stage can be moved in direction parallel to the ion-beam axis.
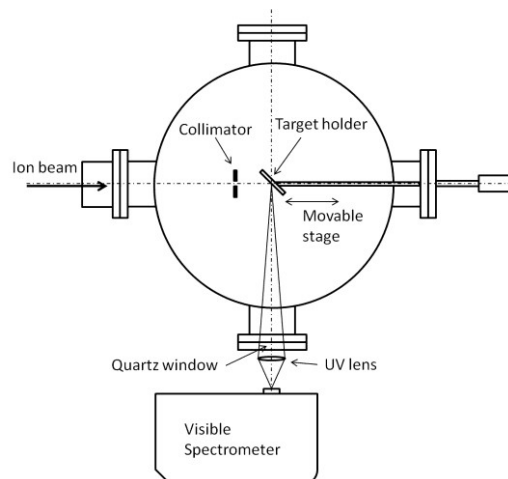

Fig.1. Schematic illustration of the collision chamber and the visible spectrometer.

After passing through a quartz window and the ultra violet (UV) condenser lens, the light from the

target sample was focused onto the entrance slit (30 μm) of a spectrometer equipped with a charge coupled device (CCD). The optical axis crosses with the ion-beam axis and the sample surface at right angle and 45 degree, respectively.

3. Result and Discussion

Fig. 2 shows a luminescence spectrum obtained by Ar^+ ion-beams at incident energy of 33 keV. Three luminescence bands are observed in the spectrum at 640-690, 540-580, and 490-520 nm, which are assigned to the intra-4f transitions from excited states of $^4F_{9/2}$, $^4S_{3/2}$, and $^4F_{7/2}$ to the ground state, $^4I_{15/2}$, respectively. Narrow emission lines of sputtered neutral Er are also identified in the spectrum. Stark component in the luminescence band at 640-690 nm are clearly resolved whereas those in the other two bands cannot be identified. Fig.3 shows the Stark spectrum in the band at 640-690 nm together with $^4F_{9/2}$ - $^4I_{15/2}$ transition wavelengths of Er^{3+} in the C_2 cation sites of pure Er_2O_3 [6]. Each peak has the Lorentzian profile having a ~10^{12} Hz width in frequency. The large line width may be ascribed to perturbation by ambient particles around the emitter, namely Er^{3+}. The broadening by mutual interaction between nearby Er^{3+}, i.e. the resonance broadening, is given by,

$$w_r = 3\pi \sqrt{\frac{g_1}{g_2}} \left(\frac{e^2 f}{4\pi\varepsilon_0 m \omega_0} \right) N, \qquad (1)$$

where g's are statistical weights of the upper and the lower Stark levels, m electron mass, f the oscillator strength of the electric-dipole transition, ω_0 the transition frequency, and N the particle number density of the emitter. The oscillator strength values of doped Er^{3+} ions in Y_2O_3 [7] and Er^{3+} number density of the perfect Er_2O_3 crystal are adopted. However, it turns out that the resonance broadening accounts only 1 % of the total width.

It is puzzling that the clean Stark spectrum of the luminescence band at 640-690 nm appears suggesting no ion-beam damage at the local area of the emitter, because SRIM code [8] simulations give 432 displacements in the target per incident Ar^+ at 33 keV. For a better understanding, variation of the intensity and the profile of the luminescence band are to be investigated changing the ion-beam current and the incident energy.
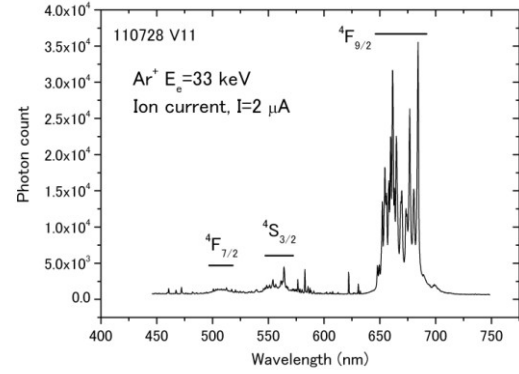
Fig.2. Measured luminescence spectrum. The spectrum was obtained using a grating of 300 Grooves/mm. Reflectivity of the grating decreases with the wavelength, and quantum efficiency of the CCD is almost uniform over the whole wavelength range of the present interest.
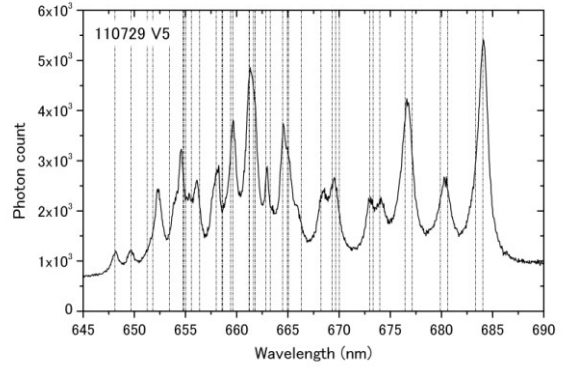

Fig.3. Stark spectrum of the luminescence band at 640-690 nm. Dash-dotted lines indicate $^4F_{9/2}$ - $^4I_{15/2}$ transition wavelengths of Er^{3+} in the C_2 cation sites of pure Er_2O_3.

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