Stimulated emission in electroluminescent CdF_2:TR^{3+} films

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It is shown that stimulated emission is produced, due to population inversion by impact excitation, in electroluminescent CdF_2:TR^{3+} (Eu, Er, Dy) films at field intensities exceeding a "threshold" value.

The possibility of producing population inversion in solids by impact excitation of an impurity was demonstrated in[1] on the basis of ZnS:Mn electroluminescent (EL) films.

We present here the results of investigations of EL films of $CdF_2:TR^{3+}$ (Eu, Er, Dy), aimed at obtaining sources of monochromatic coherent radiation on their basis.

Cadmium fluoride activated with TR^{3+} is a broad-band *n*-type semiconductor ($E_g = 6$ eV). It has a line EL emission spectrum. When activated with Eu^{3+}, for example, about 70% of the radiated energy is contained in the 590 nm line. The efficiency of an EL cell with $CdF_2:Eu^{3+}$ crystal is approximately 3×10^{-3}.[2] Investigations of $CdF_2:TR^{3+}$ films show that the EL is excited by impact excitation of the impurity ions. When the EL films are placed between electrodes making up a Fabry-Perot resonator, the radiation from the film has the interference distribution typical of light sources inside a resonator[3] (Fig. 1). The radiation-field distribution is determined by the resonator thickness.

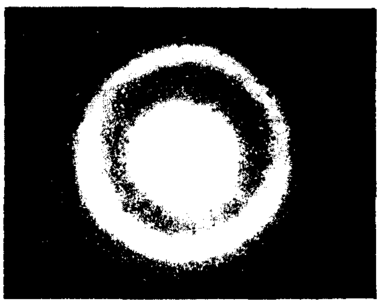

FIG. 1. Distribution of the radiation field of a CdF_2: Eu El cell at a distance 2 cm (cell area 2.5 cm^2).

The presence of stimulated emission in $CdF_2:TR^{3+}$ films when a "threshold" electric-field intensity is exceeded ($E_{thr} \sim 1.6\times10^6$ V/cm) is confirmed by a number of facts.

Passage through the "threshold" value of the intensity leads to a sharp growth (by 2–3 orders of magnitude) of the radiation intensity. A second increase of brightness is observed on the frequency dependence, just as in[3]. With increasing field intensity, brightness oscillations, not due to changes of the current, are observed in the brightness waves of the CdF_2:Eu, Er, Dy films

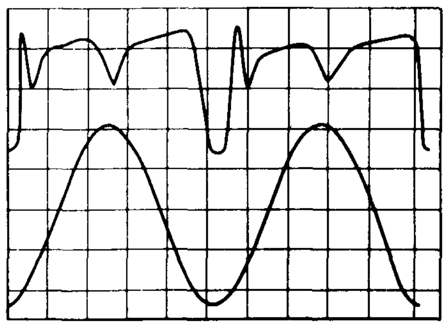

FIG. 2. Emission oscillations in the brightness waves of CdF_2: Eu films, taken from the oscilloscope screen ($E = 1.5 \times 10^6$ V/cm, $f = 15$ kHz). Upper curve—brightness oscillations; lower—exciting voltage.

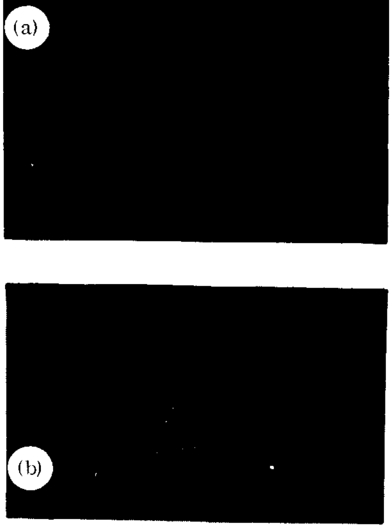

FIG. 3. Interference pattern from two slits for $CdF_2:Eu$ films: a) $E < E_{thr}$; b) $E > E_{thr}$.

at $E \approx E_{thr}$ (Fig. 2). At $E > E_{thr}$, there are no brightness waves (continuous generation), although they do exist at $E < E_{thr}$. For Eu^{3+}, for example, the luminescence damping time is sensitive to distortions of the crystal field ($\tau = 1.05 \times 10^{-2}$ and 2.9×10^{-4} sec for photo- and electroexcitation, respectively).[4] The brightness oscillations correspond to a spike regime (self-modulation of the laser radiation).[5] At $E < E_{thr}$, lines with wavelengths $\lambda = 524$, 547, 564.3, 590, 607.4, and 626.5 nm are observed in the EL spectrum of $CdF_2:Eu^{3+}$. At $> E_{thr}$, the radiation is monochromatic with $\lambda = 590$ nm ($^5D_0 \rightarrow {}^7F_1$ transition). The emission is spatially coherent. Figure 3 shows the interference pattern from two slits placed on the exit mirror (slit width 60 μ, distance between them 100 μ).

The aggregate of the experimental results indicates that population inversion on the excited levels of the TR^{3+} ions is produced in $CdF_2:TR^{3+}$ films at $E > E_{thr}$ and leads to the appearance of stimulated emission.

It is still impossible to perform clear-cut measurements of the line narrowing (the half-width of the Eu^{3+} emission line with $\lambda = 590$ nm and $T = 300$ °K is 6 Å) and of the directivity of the radiation (it is difficult to obtain TEM_{00} modes because of the considerable decrease of the electric strength of the cell with changing thickness at $E > E_{thr}$).

In conclusion, the authors are deeply grateful to the director of the Film Electroluminescence Division of the Semiconductor Institute of the Ukrainian Academy of Sciences, N. A. Vlasenko, for suggesting the line of research and for constant interest in the work.

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