CREATION OF BI-EXCITONS IN CdS BY BOMBARDMENTS OF MeV HEAVY CHARGED PARTICLES

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In order to understand the effects of charged-particle irradiation on matter, it is of importance to study the structure of the energy deposition in their tracks. Even though a great deal of works have been made on this problem for gaseous targets,[1] few works for solids have been made. It is well known that laser-excited II-VI compounds show various luminescence lines such as M, P_M and P lines at low temperatures.[2] The M line has been ascribed to the de-excitation of a bi-exciton. The P_M line and the P line have been ascribed to the inelastic collisions of two bi-excitons and two free excitons, respectively. Therefore a study of the creation of these luminescence lines induced by charged-particle bombardments of the II-VI compounds may be useful to clarify the structure of the energy deposition in solids. The purpose of the present paper is to report luminescence lines of CdS induced by bombardments with charge particles. The M line and the P line were observed and the relative intensity of the M line to the P line was found to be larger as the LET (linear energy transfer) increased. These results are explained in terms of the spatial distribution of deposited energy in the incident particle tracks.

CdS single crystals were excited by irradiation with H^+, H_2^+, H_3^+ or He^+. The beam density was about 50 nA/cm^2. The luminescence spectra were measured with a grating monochromator, a photomultiplier in a photon counting mode and a multi-scaler. The luminescence spectra of CdS induced by bombardments with 2 MeV H^+, H_2^+, H_3^+, He^+ at liquid helium temperature are shown in Fig. 1. Two luminescence lines at 2.544 eV and 2.525 eV were observed. It was concluded from the peak position and the obtained temperature dependence that these lines at 2.544 eV and 2.525 eV are the M line and the P line, respectively. It is clearly seen that the relative intensity of the M line to the P line becomes larger in the order of 1.5 MeV He^+, H_3^+, H_2^+, H^+ and 2 MeV H^+ bombardments. The result indicates that the intensity ratio of the M line to the P line becomes larger as the LET of the incident particle increases. The relation between the ratio and the reciprocal of the incident particle range, i.e the averaged LET over the range is shown in Fig. 2. It is evident from Fig. 2 that the ratio increases linearly as the LET increases. It was found that the relative intensity was substantially independent of the amount of the radiation-induced defects, although the intensity of each line was diminished slowly.

The present results are compared with the results of the laser excitation. It has been shown that with increasing the laser excitation power, the M line grows rapidly. Just before the M line tends to saturate, the P_M line starts to grow and becomes larger than the M line as the excitation power increases. Similary the P line begins to increase rapidly, just before the P_M line tends to saturate.[2]

Apparently the present tendency for the excitation densities seems to be contrary to that of the laser excitation. This result can be qualitatively understood as follows. The irradiation with charged particles does not produce uniformly distributed excitons because of the low current density and a short life time of excitons. It follows that the exciton interaction occurs only in the vicinity of ion paths. The energy deposition of the incident particles is confined within a radius of a few tens of angstroms around the paths. Therefore excitons are created more densely at the center of the ion tracks than the other part of the specimen. We consider two regions in the track: the high density region and the low density region. In the high density region the concentration of the free excitons is proportional to the root of the excitation density, because exciton-exciton interaction is the rate determing process for the exciton annihilation. Therefore the intensities of the M line and the P line are proportional to the excitation density. On the other hand, in the low density region the concentration of the free excitons is proportional to the excitation density. The present results appear to indicate that the P line is mostly emitted from the high density region, where the emission intensity is proportional to the excitation density and that the M line is mostly emitted from the low density region, where the emission intensity is proportional to the square of the excitation density.

1) A. Mousumder, Advance in Radiation chemistry 1, 1 (1969).
2) H. Satio, S. Shinoya, J. Phys. Soc. Japan 37, 423 (1974).

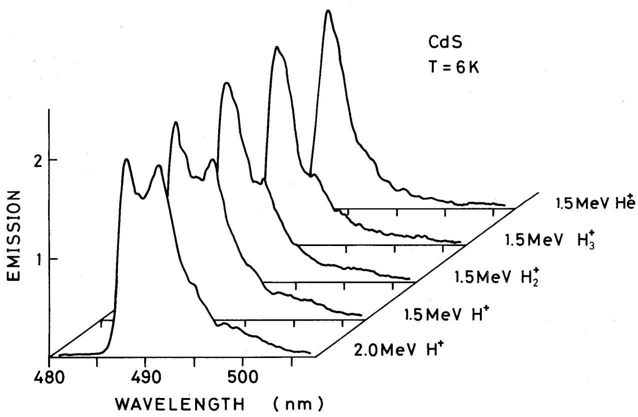

Fig. 1. Luminescence spectra of a CdS crystal induced by 2.0 MeV H^+, 1.5 MeV H^+, H_2^+, H_3^+ and He^+ bombardments at a beam current of 50 nA/cm^2. Temperature of the sample is 6K. Each spectrum is normalized at the peak of the 2.544 eV line.

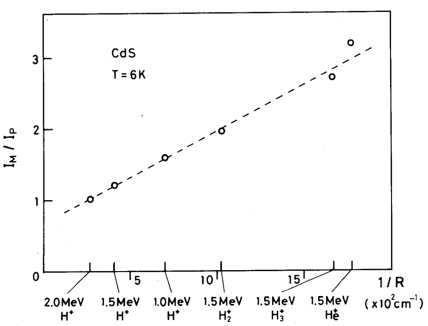

Fig. 2. Relative intensites of the M line to the P line as a function of the reciprocal of the range.