STUDY OF LUMINESCENCE IN SEMICONDUCTORS IN THE PRESENCE OF FLUCTUATIONS

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We present here photoluminescence (PL) studies of heavily doped ZnSe:N for several nitrogen concentrations. We explain the data based on a model of potential fluctuations due to a random distribution of charged impurities.

1 Introduction and Basic Theory

Wide bandgap semiconductors are presently of high interest for various device applications, in particular for devices emitting light in the green, blue, and higher energy spectral ranges. Photoluminescence (PL) has been extensively used to characterize these materials. However, although PL is generally quite well understood in low-doped materials, it is becoming increasingly apparent that heavily doped and compensated materials contain potential fluctuations, which strongly affect the PL. [1] We shall here focus on donor-acceptor pair (DAP) PL in heavily doped wide bandgap semiconductors where the PL bands are strongly shifted toward the red, as well as being strongly broadened.[2] We present data on concentration dependence of DAP PL in heavily nitrogen doped ZnSe, and explain these via a model based on the presence of potential fluctuations. [1,3]

There are two aspects of the fluctuations which are of primary importance in understanding the data. One is that the energy of an emitted photon depends not only on the pair separation, but also on the fluctuation energy, and that it is necessary to average over fluctuations, as previously shown[1]; this averaging must now be carried out to obtain the proper spectral dependence (details will be presented elsewhere [3]). The second is that only electron (hole) levels located below (above) the corresponding quasi-Fermi level μ_D (μ_A) will contribute to the PL, since the PL must originate from filled levels. These quasi-Fermi levels of course depend on the excitation intensity. For the case that $N_A >> N_D$ and that one has low excitation levels μ_A will be given by

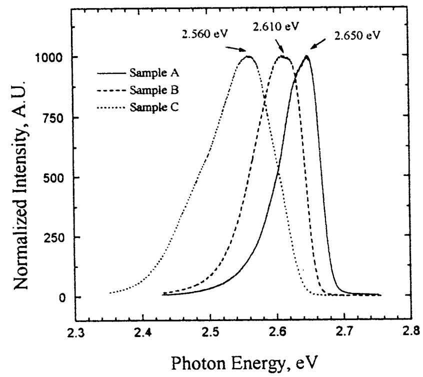

Fig. 1. Comparison of the spectra from samples A-C (see text)

Table 1: Sample characteristics

Sample	rf Power, W	$[N]$, $10^{19} cm^{-3}$
A	180	–
B	280	–
C	300	2

the dark value, and μ_D can be derived as[3]

$$\mu_D = -\sqrt{-\frac{2e^2 T_g}{\varepsilon R_s} \ln \widehat{g}}. \quad (1)$$

where $\widehat{g}$ is a normalized excitation intensity, R_s is the screening radius [1] , and T_g is freezing temperature [1].

2 Experimental Results and Discussion

We studied three different nitrogen doped ZnSe samples - samples A-C, grown with increasing rf power of the N source (Table 1). Fig. 1 shows normalized spectra of these three samples. Experimental details have been described elsewhere[4]. Of interest is a clear shift of the peak toward the red with increasing rf power. It has been shown[5] that with increased rf power, above a certain level of impurity concentration, the compensation increases. The increase in

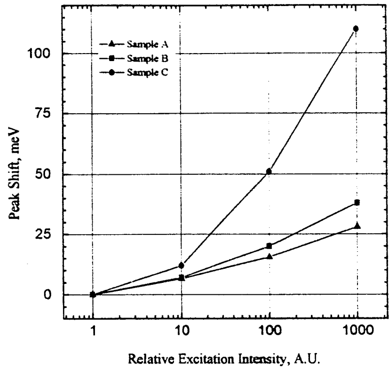

Fig. 2 Comparison of the spectral shifts for samples A-C (see Table 1) as functions of excitation intensity

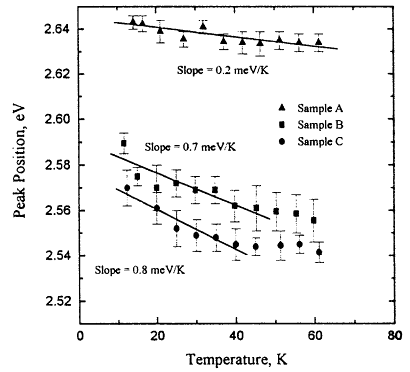

Fig. 3 Comparison of the spectral shifts for samples A-C (see Table 1) as functions of temperature

the compensation leads to an increase in the charged impurity concentration, and thus, to larger potential fluctuations. The red shift then follows from Eq.(1): increasing fluctuations give smaller R_s, causing the fermi level to go deeper into the gap, giving more lower-energy transitions, which agrees with experimental observations (Fig. 1). Furthermore, since T_g increases with compensation [1], it follows that samples with higher compensation exhibit spectra shifted more to the red as compare to others with lower compensation.

We further investigated the PL properties of these samples as a function of excitation intensity and temperature. Fig. 2 shows the peak positions for these spectra as function of the excitation intensity. Such large shifts, as well as their increasing magnitude for samples with higher dopant concentrations, are readily explained by the fluctuation model, as follows. At low excitation intensities μ_D would be relatively far from the band edge (Eq.(1)) and thus only "deeper" donors will be available for recombination. With increasing pumping according to Eq.(1) the quasi-Fermi level moves closer to the conduction band edge. Thus "shallower" donor levels will also be filled and they will contribute to the PL, resulting in the blue shift of the spectra. Changes will be larger for samples with higher dopant concentrations, since by Eq.(1) the absolute change in the quasi-Fermi level position will be greater for samples with larger fluctuations (smaller R_s). Moreover, at large pumping intensities, in addition to the above effect, one should account for a lower concentration of charged impurities, and thus for a decrease in the magnitude of fluctuations, which results in an additional blue shift of the spectra.

Further, Fig. 3 shows the temperature dependence of the peak position for these three samples. One can see that the sample with the largest fluctuations exhibits a larger shift than the other two. The red temperature shifts have previously been explained by assuming an increasing concentration of ionized species. [2] However, a slight increase in temperature (below about 60 K) would not result in a substantial increase in ionized impurities. Thus, one requires a different explanation for this phenomenon, as follows. It has been shown[6] that there is a minimum distance to which an electron (hole) should be removed from the impurity to be considered free. It is apparent that less energy is required to remove an electron from a shallower donor level than from a deeper one. Therefore, with an increase of temperature such shallow levels ionize first, which leads to a relative increase of the PL from deeper ones, giving a red shift of the whole spectrum. Clearly, the larger the fluctuations, the larger the red shift, as we indeed observed.

In summary, we have presented studies of concentration dependence of PL from heavily doped ZnSe:N. The properties of such PL have been explained by theories [1], [3] based on the fluctuation model. Explanation of temperature dependence of the peak position of the PL has been given.

3 Acknowledgements

We would like to acknowledge NSF (grant # ECS9707213) and NRC (grant # CU01637301) for partial support of this work.

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