Two-photon excited luminescence spectral distribution observation in wide-gap semiconductor crystals

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(Received 6 March 2008; accepted 3 April 2008; published online 22 April 2008)

The use of photoluminescence excited with two-photon process for characterizing the defect and impurity level in wide-gap semiconductor is discussed in this paper. Defects of polycrystalline zinc selenide (ZnSe) is observed deep inside the crystal. Two types of defects can be detected based on the spectral luminescence image. One type of defect can be seen in the entire spectrum images. Meanwhile, other types of defects can only be observed at higher energy of the spectrum, from 460 to 465 nm. This study represents works of identifying crystals defect in wide gap materials by two-photon luminescence technique. © *2008 American Institute of Physics.*
[DOI: 10.1063/1.2913760]

Wide-band gap semiconductors such as InGaN and ZnSe are promising candidates for blue lighting and laser diodes applications.[1–4] It is well known that the defects of these types of materials worsen the performances and shorten device lifetime.

Transmission electron microscopy (TEM) is the typical analysis method in identifying defects in materials. However, TEM is unsuitable for analyzing the reduction in defect densities.[5] Reports on photoluminescence technique in identifying defects are temperature dependent apparatus.[6–8] In this paper, two-photon luminescence (2PL) techniques are used to observe defects in room temperature. 2PL ensures that the excitation only occur at focal volume.[1,9–11] This allows deep level observation of the crystal placement inside the bulk, which is impossible to observe by using single-photon excitation.

The sample used is Irtran-4, polycrystalline ZnSe placed on a stage, controlled by a computer, as shown in Fig. 1. Pulse laser (Ti:sapphire, MaiTai, SpectraPhysics, 80 MHz, 100 fs) with a wavelength of 800 nm is used for the 2PL excitation source. Excitation source incident the sample using objective lens (numerical aperture=0.75, 40×) and scanned through the sample area using galvano mirrors. 2PL is collected by filtering the excitation using dichroic mirror before the photomultiplier tube. Monochromator was used in the spectral study for analyzing the defects.

Figure 2 shows the layer by layer images of polynomials ZnSe starting from the depth of 42 μm. The image has 256×256 pixels with 1 μm/pixel. The images are obtained for every 500 nm along the optical path. We compared all the images with the images taken with single crystalline ZnSe (not shown in this report). Single crystalline ZnSe do not show difference in intensity distribution which can be seen for polycrystalline ZnSe.

Black lines were observed in the image bordering two adjacent ZnSe crystals. The crystals organized side by side and the difference of luminescence intensity for each crystals can be distinctly observed even at the deep level images shown in the image for 62 μm deep, shown in Fig. 2. While most of the places are brightly illuminated, the right side shows a black area (no or low luminescence is detected). This black area indicates defect of the crystal.

Figure 3 shows images with different wavelengths of luminescence light filtered with monochromator. Each image was taken for wavelength with 1 nm spacing from 460 to 481 nm. From the images, two types of defects can be identified. One type of defect is shown in all images. This type of defect is shown as a small round hole that randomly exists around the low half of all images in Fig. 3.

Figure 4(a) shows five points taken with its respective spectrum distribution profile run through a monochromator in Fig. 4(b). At point 5, which correspond with defect observed in all the spectrum as described earlier, the luminescence of this area is small compared to other places at the band gap wavelength of 467 nm (ZnSe band gap: 2.67 eV). Thus, we believed that this defect is responsible for the defect of grain powder ZnSe during the maturing process. Accompanying impurities that followed during the maturing process lead to self-luminescence at longer wavelength recording to donor-acceptor pairs as in Ref. 12.

Another type of defect is observable as black lines crossing through images for the cases with wavelengths of 460–465 nm in Fig. 3 This corresponds to points 3 and 4 in Fig. 4. Those black lines indicate second type of defect which occur after the maturation process probably during the pressing that leads to defect. The small shift of lower

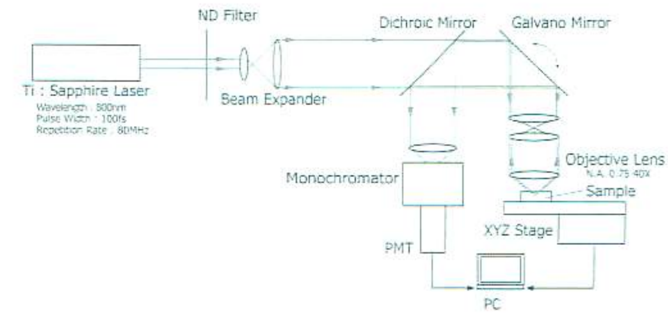

FIG. 1. (Color online) Experimental configuration on ZnSe using two-photon luminescence.

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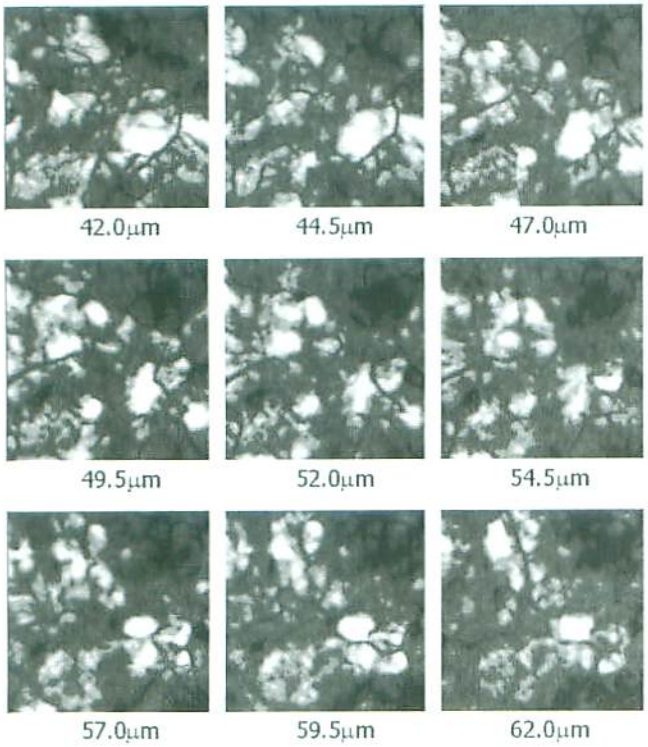

FIG. 2. (Color online) Cross-section luminescence intensity distributions image of polynomials ZnSe.

energy is due to the transition of the two electrons of the donor in the crystal.[13] This leads to the observation of peak at the same wavelength with lower luminescence energy.

We presented 2PL excitation spectral luminescence based on a single wavelength. It is intriguing to study various

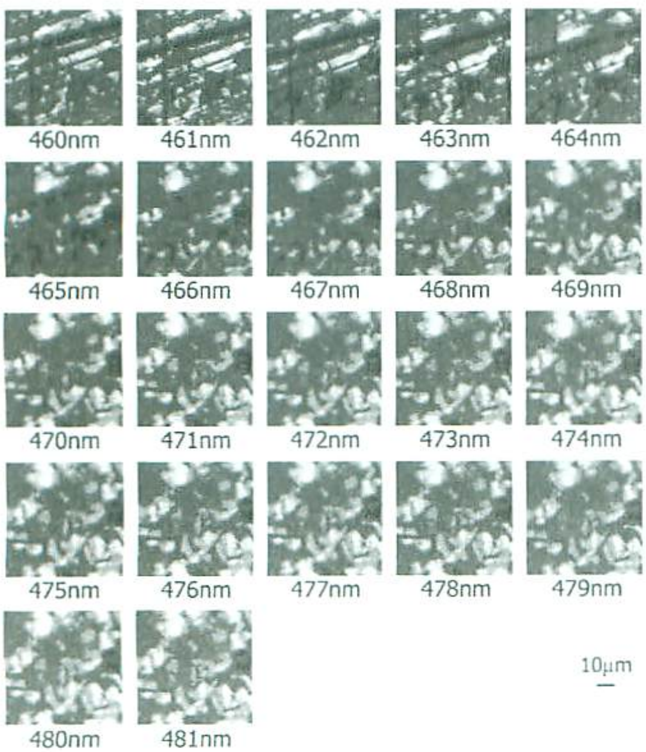

FIG. 3. (Color online) Spectral distribution images of polynomials ZnSe crystal filtered by monochromator.

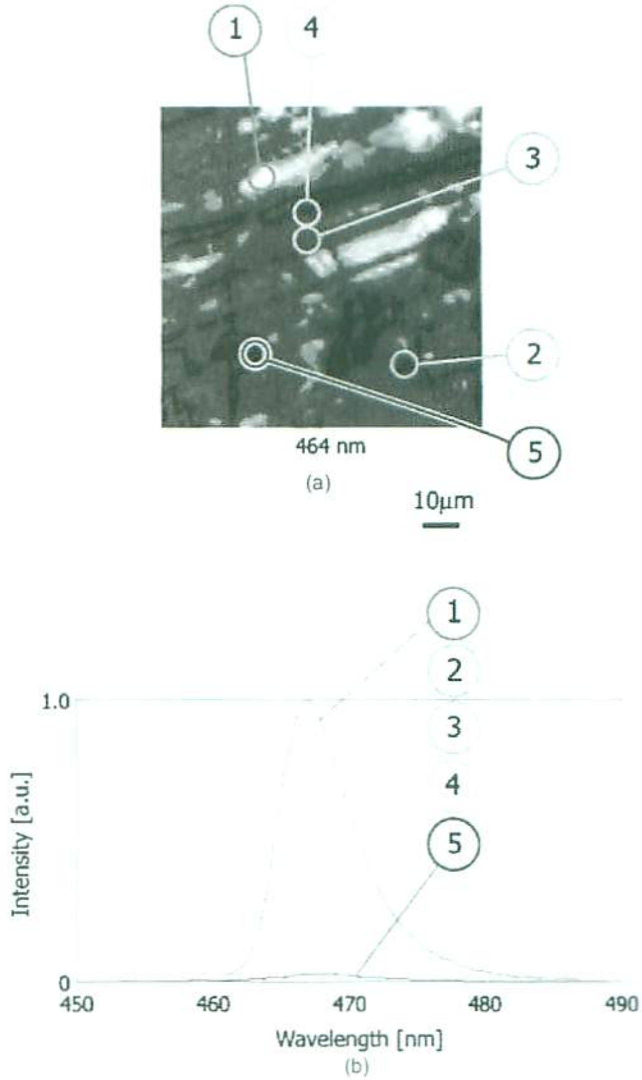

FIG. 4. (Color online) Different point area for 1–5 in (a) and for spectral distribution in ZnSe (b).

excitation wavelengths and its differences of spectral distribution in relation to defining the defects. Perspective of comparison between 2PL and single-photon excitation are also very interesting to be discussed.

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