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Том 2

ЛЮМИНЕСЦЕНЦИЯ ГЕКСАГОНАЛЬНОГО НИТРИДА БОРА, ОБЛУЧЕННОГО ИОНАМИ ГЕЛИЯ, УСИЛЕННАЯ ЭЛЕКТРОННЫМ ОБЛУЧЕНИЕМ

ELECTRON IRRADIATION ENHANCED LUMINESCENCE OF HELIUM ION-IRRADIATED HEXAGONAL BORON NITRIDE

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Hexagonal boron nitride (h-BN) is a wide bandgap semiconductor, and point defects in this material are considered as promising candidates for single photon emitters [1]. The luminescence spectrum of h-BN consists of several emission bands, and the most investigated bands are: 650 nm (1.9 eV), 320 nm (3.9 eV) and 215 nm (5.8 eV). The energy of the last one is close to the band gap of h-BN, so this band is usually attributed to indirect exciton [2]. The origin of two other luminescence bands is still under discussion, and they are usually attributed to diverse point defects such as vacancies or antisite defects for 1.9 eV [3] and carbon and oxygen impurities for 3.9 eV [1, 4]. Fabrication of abovementioned single photon emitters requires some method of control of the concentration of point defects in hexagonal boron nitride. Several methods of such control are considered, and one of the most promising is irradiation with a focused ion beam. Though several attempts to use ion irradiation for the fabrication of single photon emitters were made [5, 6], the process of defect formation in this case is not well understood yet. In our previous work we have showed that irradiation with a focused helium ion beam at certain ion fluence might lead to increase of the intensity of 1.9 eV emission band [7]. In this work we present new results of the investigation of the evolution of cathodoluminescence of helium ion irradiated h-BN under subsequent prolonged electron irradiation.

Thin crystals of hexagonal boron nitride were prepared from high quality single crystal by means of exfoliation and transfer onto a substrate. Silicon nitride film on silicon was used as the substrate. The thickness of the sample was measured by means of atomic force microscopy. Helium ion microscope Zeiss Orion Plus was used for helium ion irradiation. The samples were locally irradiated with 30 keV He ions at an ion fluence ranging from 5×10^{13} cm^{-2} to 3.2×10^{15} cm^{-2}. Cathodoluminescence (CL) investigations were performed with SEM Zeiss Supra equipped with Gatan MonoCL 3 system at an electron beam energy and current of 5 keV and of 3 nA respectively.

CL spectrum of pristine hexagonal boron nitride (figure 1) consisted of three bands: an intense peak at 215 nm, a band at 640 nm and broad and a weak band with a maximum at 320 nm.

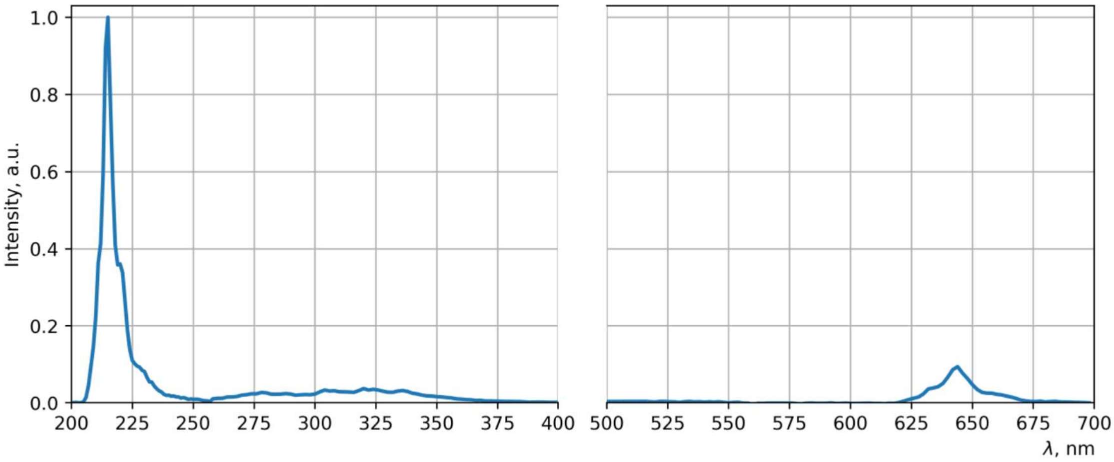

Figure 1. CL spectrum of 190-nm-thick h-BN on silicon nitride.

CL maps acquired at three mentioned spectral band wavelengths in the initial sample are depicted in figure 2 a-c. Then, the series of raster scans of rectangular areas (3x25 mkm) on the sample surface were performed with focused helium ion beam. Ion irradiation resulted in a decrease of the intensity of all CL bands as it can be clearly recognized from CL maps in figure 2 d-f, where the irradiated areas are seen as dark stripes.

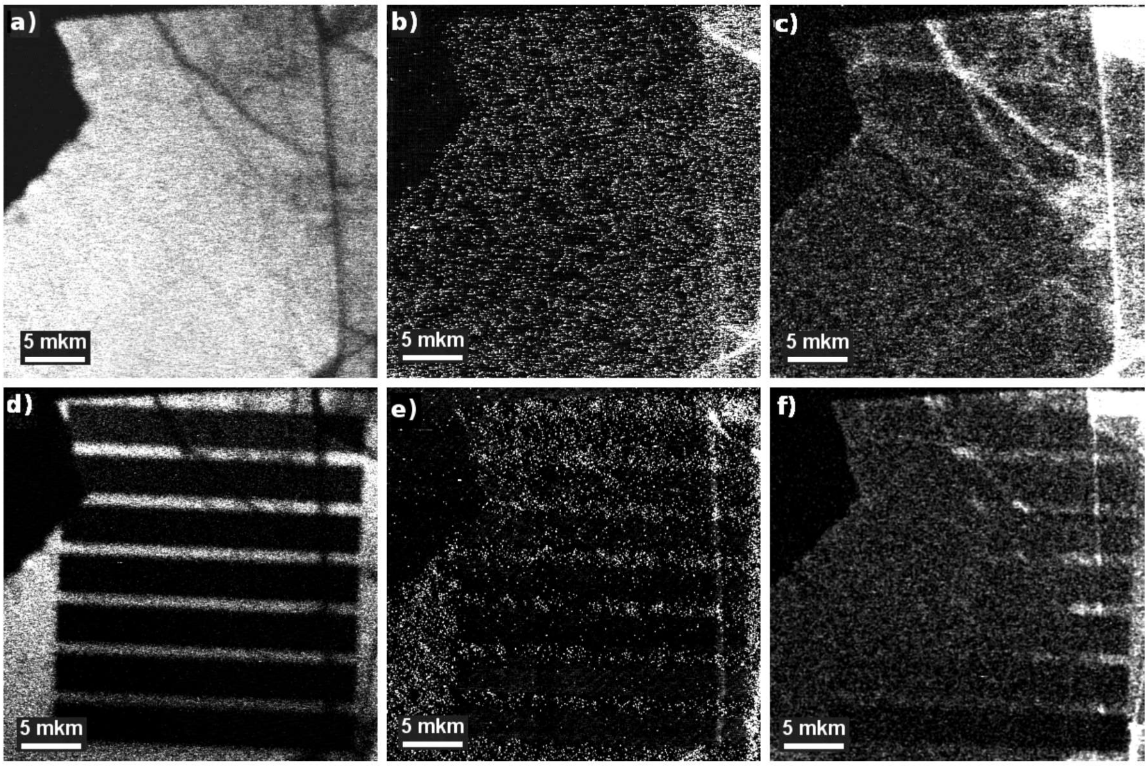

Figure 2. Monochromatic CL maps of pristine (a-c) and ion-irradiated (d-f) samples, acquired at different wavelengths: a), d) - 215 nm, b), e) - 320 nm, c), f) - 650 nm. The ion fluence starts from 5×10^{13} cm^{-2} for the top stripe doubling then each previous strip value up to 3.2×10^{15} cm^{-2} for the lowermost stripe.

Therefore, we can conclude that ion-induced defects in h-BN act as non-radiative recombination centers. However, as it was previously observed [8], the CL measurements themselves might have a significant effect on the intensity of 640 nm band, so the dependence of this intensity on electron beam excitation time was measured for each ion-irradiated rectangle. It was found that the intensity of this CL band had a non-monotonic character upon the duration of the continuous electron beam irradiation: the intensity of the CL band first increased quickly and then decreased slowly. The intensity of the same CL band for pristine h-BN remained almost constant during electron irradiation.

The dependences of CL intensity on time of electron irradiation for all ion-irradiated rectangles were approximated with a sum of two exponential functions, one for rapid growth and another one for slow decay. It was found that the time constants are roughly proportional to helium ion fluence, which the rectangle was irradiated with. This dependence can be explained if the ion-induced defects turn into the luminescence centers of this CL band under electron beam irradiation. The process of the formation of new centers, responsible for 1.9 eV CL, can be easily explained if such centers are antisite complexes $V_N N_B$ [5] that can be formed from boron vacancy, which in turn was formed by ion irradiation.

Thus, helium ion irradiation of hexagonal boron nitride can be used not only for quenching of its luminescence by means of generation of defects, as has been shown in [5], but also for the preparation of non-equilibrium state with a high concentration of defects, which can be converted into new luminescence centers by means of electron beam treatment.

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