Excitation power dependence of the photoluminescence emission in 6H silicon carbide

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Silicon carbide (SiC) is a wide bandgap semiconductor which is used industrially for high power electronics. Recently it has attracted considerable research attention for optical applications such as white lighting [1] and as a host of quantum emitters [2]. Its exceptional properties such as high thermal conductivity (4 times that of GaN) and lattice matching drive its use as a substrate for high power GaN based LEDs. Due to its excellent physical and electrical properties as well as progress in the photoluminescence (PL) emission, SiC is a promising candidate to be used as light conversion material for laser lighting which is projected to be the next generation of energy efficient lighting solution [3]. A key requirement and bottleneck in the laser lighting development is a light conversion material that can withstand the high thermal load due to high laser flux. The potential application of SiC for laser lighting requires excitation power dependent examination of the light conversion characteristics.

In this abstract the excitation power dependence emission property of Al-N co-doped 6H SiC epilayer grown by fast sublimation growth process is summarized. The concentrations of N and Al are 1.1×10^{19} and 1.8×10^{18} cm^{-3} respectively as measured by a time-of-flight secondary ion mass spectroscopy. A continuous wave laser diode emitting near 378 nm with a maximum output of 400 mW is used for excitation. The excitation beam is focused tightly on the sample to a beam spot size of about 112 μm using a lens and the PL signal is collected by a microscope objective and is coupled to an Andor spectrometer.

The log-log plot of the relative peak PL intensity vs the excitation power for several temperatures is shown in Fig. 1(a). It can be observed that the PL emission intensity follows a power law dependence on the excitation power at all temperatures. A power law dependence of emission on excitation power has been observed in other semiconductors such as CdTe where $I_{PL} \propto L_{ex}^{k}$. The power exponent can have a value of $1< k<2$ for exciton transitions and $k<1$ for free-to-bound and donor-acceptor pair (DAP) transitions [4]. The power exponent of $k<1$ in the measurements shows that the prominent emission mechanism in the sample is DAP recombination. The decrease in the peak intensity with increasing temperature is due to the reducing capture rate of photoinduced carriers by the radiative centers. The decrease in the power exponent at higher temperatures can be explained by a more efficient Auger recombination as temperature increases. A modelling of the carrier recombination processes indicates that prevalence of Auger recombination in the carrier transition dynamics results in the sublinear excitation power dependence. For practical application of laser lighting the power exponent shall be as close as possible to one to maintain same conversion efficiency of at low powers at high excitation levels. The theoretical model based on rate-equations shows that this can be achieved by increasing the donor and acceptor concentrations.

Furthermore we observed a shifting PL band as we increase the excitation power for the first time in SiC. As shown in Fig. 1(b) the emission peak (ω_p) shifts by more than 30 meV as the incident excitation power changes from 4.7 to 225 mW. The inset shows the peak spectra near the emission peak. This can be explained by the formation of fluctuating potential due to randomly distributed charged dopants which leads to spatially separated potential wells. In this case the emission peak increases logarithmically with the excitation power where the relationship can be expressed mathematically as, $I_{ex} \propto \exp(\omega_p/\gamma)$ [5] where γ is the proportional to the depth of the potential well created by the ionized dopants and is the slope in Fig. 1(b). An increasing excitation screens the fluctuating potential by the photo-induced holes and electrons shifting the emission band to a higher energy. The amount of shift depends on the density and extent of the ionized dopants and this technique can be used to determine the level of compensation.

In summary a power law dependence of PL intensity on the excitation power with power index of less than one is observed in SiC for the first time. In addition a shifting band where the peak energy shifts by more than 30 meV with increasing excitation power is measured with a peculiar logarithmic dependence which can be explained by the formation of localized potential wells due to randomly distributed ionized impurity in highly doped and compensated semiconductors. This property can be used to investigate the ionized impurities and charge transport properties of highly doped SiC and compensated layers in its optical and electronical applications.

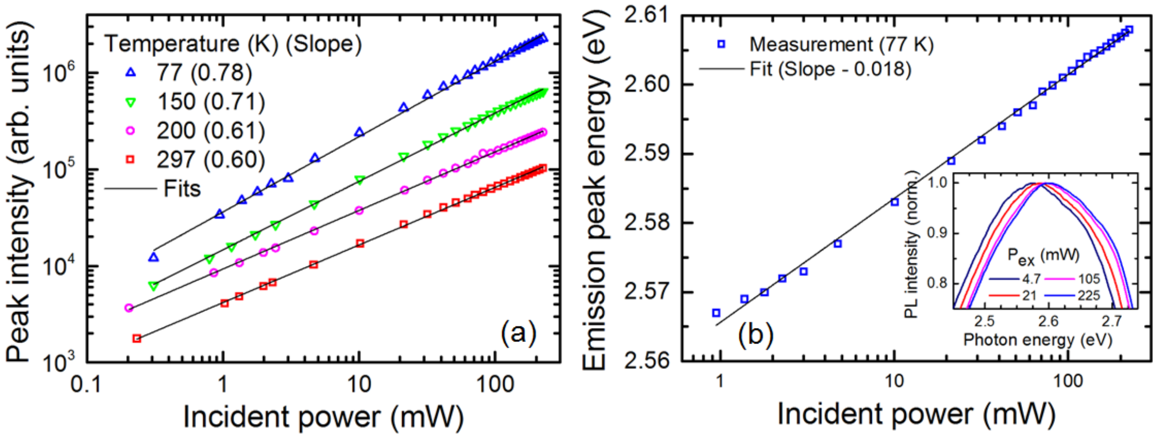

Fig. 1. (a) Log-log plot of the relative peak intensity of PL emission versus the excitation power at several temperatures, (b) emission peak energy versus logarithm of excitation power at 77 K for an Al-N co-doped sample. The inset in (b) shows the emission spectra near the PL peak at selected incident excitation powers. The solid black lines are fits.

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