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Thermally Stimulated Luminescence in 6H Fluorescent SiC

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Fluorescent silicon carbide (f-SiC) is the emerging material for white light-emitting diodes (LED) thanks to its high conversion efficiency from near-ultraviolet (NUV) to visible light [1-2]. However, the procedures of the donor-acceptor pair (DAP) recombination, which plays the key role for the wavelength conversion of the f-SiC material and determines the internal quantum efficiency (IQE), have not been precisely interpreted yet. The occupancy conditions of the electrons and the holes on the different sites [3] of the donor levels and the acceptor levels respectively vary with different f-SiC samples (e.g., 2 types of cubic sites and 1 type of hexagonal sites of the donor levels for 6H SiC), and the dominance of the DAP recombination process is site-dependent [4], hence the tuning of the dominant occupancies of the electrons and the holes to enhance the DAP procedures is an important issue during the crystal growth and is able to essentially improve the IQE of the 6H f-SiC material.

In this paper, we demonstrate the characterization of the dominant occupancies of the electrons on the donor levels of the two different n-type 6H f-SiC samples by using thermally stimulated luminescence (TSL). TSL has been applied for the experimental characterization, since TSL has no requirement of contact preparation for samples which is quite time-consuming, making the advantage of the TSL method beyond the conventional defect levels characterization methods like deep level transient spectroscopy [5]. We further theoretically studied the measured TSL results based on the monomolecular and bimolecular thermal activation energy model developed by Halperin A. et al. [6] with our own modification according to the special case for the f-SiC material. The modelled TSL curves fitted well with the measured TSL curves regarding to both the line shape and the actual TSL intensities.

Two boron (B) and nitrogen (N) co-doped n-type 6H f-SiC samples, ELS118 (N: 9.2×10^{18} cm^{-3}, B: 5.2×10^{18} cm^{-3}, epilayer thickness: 40 μm) and ELS569 (N: 2.38×10^{18} cm^{-3}, B: 1.1×10^{18} cm^{-3}, epilayer thickness: 150 μm), were grown by using fast sublimation growth process [1]. For the TSL measurements, firstly the sample was cooled down to 25 K in a vacuum chamber. Second, the sample was excited by the X-ray source (75 kV and 18 mA) within 6 cycles with 30 sec per cycle. Then the cryostat started to be heated up with the preset heating rate (the actual controlled heating rate - ELS118: 0.168 $K.s^{-1}$, ELS569: 0.151 $K.s^{-1}$). The thermally stimulated photons transported through a chopper in order to eliminate the background noise and then collected by the photomultiplier with the lock-in amplifier, the user interface on the computer for the TSL measurements was developed by i-MEET, University of Erlangen-Nürnberg using LabVIEW.

Immediately after the X-ray excitation of the sample, most of the generated electron-hole pairs recombine spontaneously, where the radiative recombination is observed as photoluminescence [7-8]. During the heating procedure, the trapped electrons on the donor levels will be thermally excited to the excited states of each donor levels or directly be excited into the conduction band (this part of electrons are called the free charge carriers). Then the excited electrons (on the excited states donor levels or in the conduction band) can either be re-trapped by transforming to the ground states of the donor levels or recombine with the trapped holes on the acceptor levels (recombination centers), of which the radiative recombination is recorded as the TSL curves, the explicit descriptions of the above excitation and heating process of the n-type samples are shown in Fig. 1. Based on the above physical process of the TSL spectroscopy, we implemented the thermal activation energy model [6] with the modification on the expression of the free charge carriers similar with Stiasny T. et al. [9]. In our case it is possible that free charge carriers could be accumulated during the heating process, therefore free-to-bound recombination [10] was enabled in the modeling for the TSL of the 6H f-SiC material.

Moreover, we treated the recombination probabilities, re-trapping probabilities and the frequency factor as the functions of temperature.

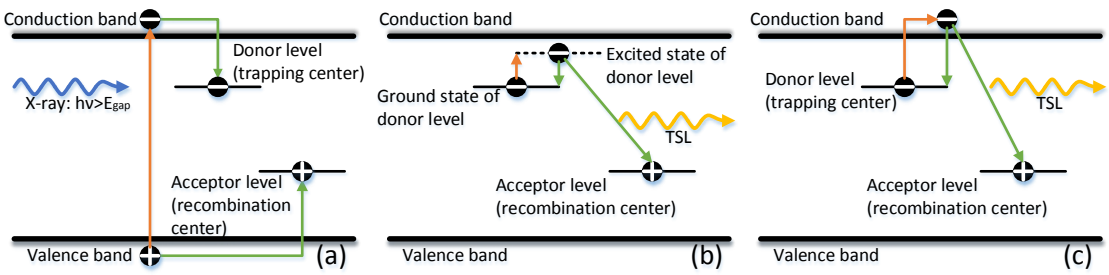

Fig. 1. Energy diagrams of: (a) X-ray excitation of the n-type sample; (b) The trapped electrons being thermally excited to the excited state of the donor level; (c) The trapped electrons being thermally excited into the conduction band.

The results of the numerical simulation have fitted well with the corresponding main TSL peaks of each sample as shown in Fig. 2, where the whole TSL curves with y-axis set as linear mode are shown in the inset of Fig. 2. The parameters extracted from the fitting in Fig. 2 are shown in Table I. The TSL measurement data were successfully fitted with a model that assumed the presented physical processes. Detailed analysis will be presented at the conference.

In conclusion, we have investigated the dominant occupancies of the donor levels of two 6H f-SiC samples by applying the TSL method and the corresponding numerical simulation, and the radiative recombination is found to be dominated by both the free-to-bound and the DAP recombination related to hexagonal sites on donor levels. The strong re-trapping process was found on both samples.

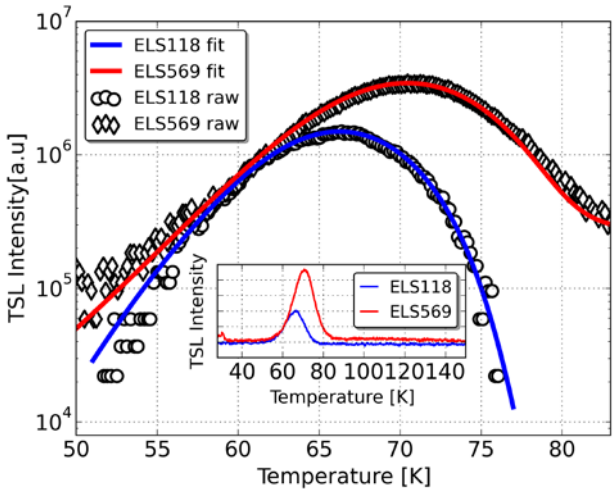

Fig. 2. The main plot: the measured and simulated main TSL curve of the two 6H f-SiC samples, the inset: the whole TSL curves with y-axis set as linear mode.

Table I. The extracted parameters from the TSL curves fitting, note that the subscript "0" indicates the intial values.

a) E: effective donor level;
b) δ: the index indicating whether the TSL process is retrapping-dominant or recombination-dominant;
c) m_0/N_0: ratio between the density of the recombination centers and the total density of the donors.
d) $\rho = m_0/n_0$: ratio between the density of the recombination centers and the density of the occupied donors.

Param.	E [meV]	δ	m_0/N_0	ρ
ELS118	43.4	0.41	2×10^{-10}	2
ELS569	42.3	0.48	4×10^{-11}	2.3

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