Photoconductivity study of Mg and C acceptors in cubic GaN

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Abstract. We present the results of direct photoionization studies of Mg and C doped cubic GaN. Photocurrent was measured with use of a Fourier transform spectrometer in the spectral range of 50 to 500 meV. The investigated samples were grown on (100) GaAs substrate by plasma-assisted molecular beam epitaxy, with room temperature hole concentrations varying from $1.4 \cdot 10^{16}$ to $4.5 \cdot 10^{17}$ cm ^{3}. No structure in the broad-band photocurrent spectra was observed. The onset of the photoionization band was found to start at about 150 meV in a lightly doped samples and move towards lower energies with increasing hole concentration, indicating the formation of an impurity band.

Despite the progress in the development of devices based on cubic phase GaN [1] p-type doping remains an important issue. The hole binding energies of various acceptors, such as and C and were never directly measured and only estimated from photoluminescence or Hall effect experiments. The experimental data obtained from Hall effect measurements yield a wide range of thermal activation energies depending on the concentration and degree of compensation, while the interpretation of the results of optical studies, such as donor-to-acceptor transitions, require assumptions regarding the donor involved. In this paper we report direct measurements of acceptor photoionization in cubic GaN.

The samples studied were Mg and C doped cubic GaN layers ($\approx 1\mu$m thick) grown by rf plasma assisted MBE on GaAs substrates (the details of sample growth can be found elsewhere [2, 3]). The room temperature mobility and hole concentration as obtained from Hall effect measurements are listed in Table 1. Photocurrent was measured with use of a Keithley 428 current amplifier and a BOMEM DA8.23 Fourier Transform infrared spectrometer in the spectral range of 50-500 meV. The sample was placed on a cold finger of a Cryoflow cryostat and illuminated with the KBr split beam of the Globar light source. Voltages ranging from 10 to 35 V were applied (measured dc currents were in the range of 1-100 μA).

Typical raw photocurrent spectra are shown in Fig. 1, as compared to the reference spectrum of the Globar light source passing through the beam splitter taken with an MCT detector. No sharp features in the photocurrent spectra were observed (the apparent structure is due to absorption of the beam splitter and water vapour). In the highest carbon doped sample (*e*) no hole freeze out was observed down to 10 K, in the slightly lower doped sample (*d*) a freeze out was obtained only below 60 K. No influence of applied voltage on the shape of the spectra was observed. In the temperature dependence in the range of 20-120 K only a change in intensity was found, related to the change in hole mobility.

TABLE 1. Sample parameters

Sample label	dopant	RT hole concentration (cm ^{3})	RT mobility (cm^2/Vs)
a	Mg	$1.4 \cdot 10^{16}$	270
b	C	$3.0 \cdot 10^{16}$	178
c	C	$4.7 \cdot 10^{16}$	143
d	C	$3.9 \cdot 10^{17}$	133
e	C	$4.5 \cdot 10^{17}$	177

The raw spectra divided by the reference spectrum are shown in Fig. 2. Though no correction for the MCT detecor response was done we found that the onset of the photocurrent spectra can be well described by the Lucovsky photoionization formula for a purely electronic cross section, $\sigma\ (E - E_I)^{3/2}/E^3$, where E_I is the ionization energy. The ionization energy determined with use of the formula was found to be the same in all the lightly doped samples (*a*, *b*, and *c*), $E_I = 147 \pm 5$ meV, independent of the intentional dopant (C or Mg), and characterizes most probably the native acceptor of unknown, so far, origin. The ionization energy is very close to the value of 130 meV estimated for this acceptor from optical studies [4]. We have found no photoionization band related to the Mg acceptor that would lead to increase of the photocurrent. In contrast, in the Mg doped sample a decrease of photocurrent is seen with an onset about 240

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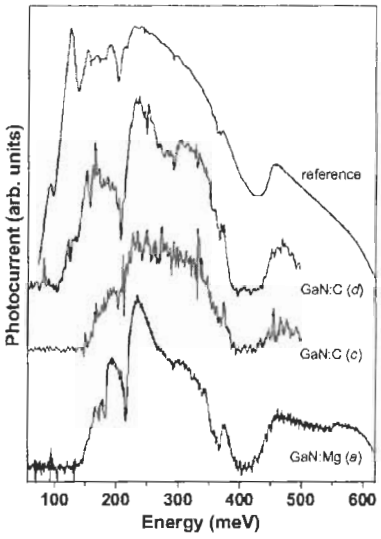

FIGURE 1. Photocurrent raw spectra compared to the reference spectrum of the Globar light source taken with an MCT detector (upper trace). The data shown were measured at 80 K (samples *a* and *c*) and 50 K (sample *d*).

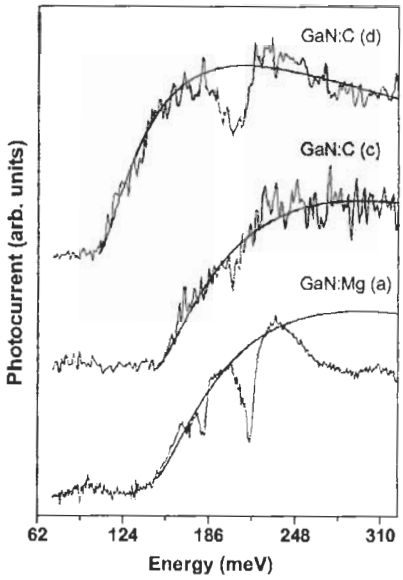

FIGURE 2. Raw spectra divided by the reference spectrum. The smooth lines show the fit with the Lucovsky photoionization formula for ionization energies of 147 ± 5 meV for samples *a*, *c* and 105 ± 5 meV for sample *d*.

meV, indicating a competing, defect related absorption process not found in carbon doped samples. (The feature around 220 meV is due to absorption in the instrumental setup.) In carbon doped samples we observe a decrease of the photoionization energy with increasing hole concentration. In particular, in sample *d* the photoionization energy moves to 105 ± 5 meV. We relate this to impurity band formation, which is supported by the lack of carrier freezeout at higher C concentration (sample *c*).

In summary, we presented the results of direct photoionization studies of Mg and C doped cubic GaN. The photocurrent was found to be dominated by the native cubic GaN acceptor in lightly doped samples. In heavily doped samples formation of an impurity band was observed.

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