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GaN characterizations using femtosecond optical pulses

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The demonstration of high-brightness green-UV light-emitting diodes and laser diodes has established GaN as key materials for optoelectronics operating in the green-UV wavelength range.¹ Despite the progress in the device developments, the basic properties of GaN are still poorly understood. Due to their high peak powers and short pulse widths, femtosecond optical pulses have become major tools for material characterization. In this presentation, we will report on the characterization of GaN using femtosecond optical pulses. First, we have measured below bandgap nonlinear refractive index n_2 using Z-scan techniques.² High n_2 value on the order of -10^{-12} cm²/W was measured, which indicates potential applications in all optical control and ultrafast optoelectronics. Second, we have measured two-photon absorption coefficient (β_2) using pulsewidth autocorrelation. The measured β_2 is on the order of 3 cm/GW (for midgap wavelengths), which is higher than that of diamond and one order of magnitude larger than that of fused silica. The large two-photon absorption coefficients and broad band applicability make GaN and related materials excellent candidates as nonlinear crystals for IR-UV femtosecond pulsewidth measurements. Third, using femtosecond thermomodulation spectroscopy, we have studied the bandtail states in heavily n-typed doped GaN samples. The experimental results agree well with a model proposed by P.K. Chakraborty and J.C. Biswas.³

The GaN film was grown by MOCVD on c-plane sapphire in an atmospheric pressure reactor. After annealing the substrate at 1050°C, a 525-Å-thick nucleation layer was deposited at 600°C. The temperature was then raised to 1080°C to grow unintentionally doped GaN layer of 2 μ m thickness. The resulting n-type carrier concentration was 1.2×10^{17} cm⁻³. The measured electrical mobility constant was 620 cm²/V-s, indicating excellent epitaxial quality. For highly doped samples, Si doped GaN layer of 1000 nm thick-

CTu14 Fig. 1. Normalized Z-scan transmittance of GaN measured using femtosecond pulses at $\lambda = 367.5$ nm. The solid line is a theoretical fit.

CTu14 Fig. 2. Autocorrelation trace of a femtosecond pulse at $\lambda = 720$ nm measured using differential transmission in a GaN film. The dotted line is a Gaussian fit.

ness was grown following an unintentionally doped GaN layer of 1070 Å thickness and was finished with a 6 nm thick undoped GaN cap layer. The resulted n-type carrier concentration was on the order of 2×10^{18} cm⁻³. The crystal structures were wurzite.

Figure 1 shows an example of the measured Z-scan traces in unintentionally doped GaN films using 367.5 nm optical pulses, frequency-doubled from IR pulses generated by a modelocked Ti:sapphire laser, with a pulsewidth of 180 fs. The induced phase changes varied linearly with incident intensities. n_2 value of -1.2×10^{-12} cm²/W was thus derived. The measured value is comparable to that of GaAs, which is also on the order of -10^{-12} cm²/W for below-bandgap wavelengths.⁴ We will discuss the effects of resonance enhancement and doping in our presentation.

The conventional autocorrelator based on second harmonic generation are widely used for pulsewidth measurements. However, this technique is not applicable for UV wavelengths due to absorption of the generated second harmonic signals in available nonlinear crystals. Autocorrelation based on two-photon absorption in diamond⁵ and fused silica⁶ were proposed and demonstrated for UV wavelengths. Utilizing two-photon absorption for autocorrelation also has the advantages of less wavelength dependence and insensitive to polarization. We have investigated the applications of GaN in pulsewidth autocorrelation. Our experimental setup is similar to a conventional autocorrelator. Figure 2 shows an example of the measured differential transmission ($\Delta T/T$) trace using 720 nm pulses generated from a modelocked Ti:sapphire laser. The measured transmission change corresponded to a β_2 value of 3 cm/GW, which is higher than that of dia-

CTu14 Fig. 3. Thermo-modulated transmission changes vs. electron energy for n-type doped GaN with a doping density of 2×10^{18} cm⁻³. The dotted line is a theoretical fit.

mond⁵ and one order of magnitude larger than that of fused silica.⁶ Wavelength-dependent studies will also be presented.

The bandtail states in heavily n-typed doped GaN was studied using femtosecond thermo-modulation spectroscopy. Electron distribution was heated through free carrier absorption of IR excitation pulses while thermo-modulated transmission corresponding to different electron energy position was probed by delayed UV pulses. Figure 3 shows the measured transmission changes vs. electron energy for a heavily doped sample. An excellent fit (dotted line in Fig. 3) can be obtained using equation 31 of Ref. 3 with an impurity screening potential of 40 meV. More experimental details and discussion will be presented.

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Optical characterization of InGaN/GaN quantum well structures with Si-doped barriers

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The effect of Si doping on the optical properties of GaN and InGaN/GaN quantum well structures has recently attracted attention in relation to the optimization of light emitters based on GaN. The most striking effect of Si doping is the increase of the near band edge emission efficiency in GaN epilayers and multiple quantum well structures (MQWs). In GaN and InGaN epilayers the effect of Si doping was explained as being due to the competition between nonradiative trapping and trapping at donor levels,¹ and to strain relief with the inclusion of Si atoms.² Si doping in the barriers of InGaN/GaN MQWs has also been associated with improved interface uniformity³ and screening of the strain-induced piezoelectric field.⁴ In the present work we explain the effect of Si doping by the compensation of deep states and enhanced role of shallow levels due to the diffusion of dopant atoms into the