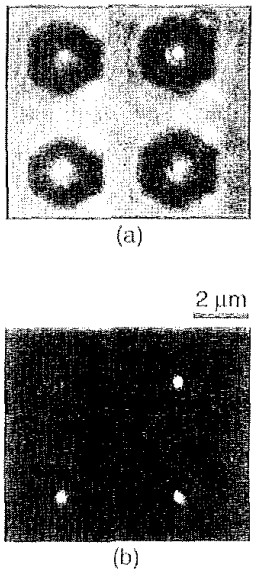

CWB6 Fig. 3. (a) Reflective image and (b) micro-PL image at the peak wavelength of 430 nm.

half maximum (FWHM) is 290 meV. The PL intensity of InGaN QD structure is smaller than that of GaN emission peak at 363 nm, because the volume of InGaN QD structure is much less than that of GaN layer in this sample.

The micro-PL intensity images were taken at room temperature, using a conventional optical microscope.[4] The samples were excited uniformly by a mercury lamp with the peak wavelength of 365 nm, and the excitation density was 1 W/cm^2. The emission passed through a band-pass-filter with the band width of 5 nm and was detected by an electrically-cooled charge coupled device (CCD) camera. The spatial resolution was as high as 150 nm. Figure 3 shows the reflective image and micro-PL intensity image at the wavelength of 430 nm.

In Fig. 3(b), the strong emission was observed only from the top of the structure. The FWHM is comparable to the spatial resolution (150 nm). This fact indicates that the localized states were realized on the top of the hexagonal pyramids and these localized states are due to InGaN QD structure.

In summary, we have fabricated InGaN QD structure by SAG technique. The micro-PL intensity images show the emission area is only the top of the structure, therefore, InGaN QD structure is formed on the top of the hexagonal pyramids.

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CWB7 **9:30 am**

Oxidation enhanced optical response on gallium nitride

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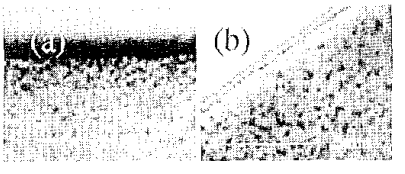
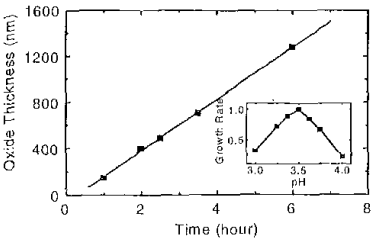
The wide bandgap III–V nitrides have been long recognized as a material system of outstanding opto-electronic properties compared with those of group IV and II–VI materials. Rapid development in the epitaxial growth, doping control, and device processing on group III nitride has brought in a plethora of research activity ranging from material property investigation to device application. Although much attention has been emphasized on the device application, little has been devoted to the issues of surface passivation on GaN. Due to the lack of native oxidation techniques on GaN, common practice has pursued the use of silicon oxide (SiO_x) or silicon nitride (Si_xN_y) as the dielectric coating in the processing of GaN-based emitters and detectors. Recent investigation, however, reveals that the deposited SiO_x layer can result in a significant degradation of the photo-luminescence (PL) intensity due to the incorporation of oxygen as non-radiative recombination centers in GaN.[1] In comparison, deposition of Si_xN_y has found no improvement on the PL performance at all. Gallium oxide, characterized by the low refractive index and high static dielectric constant, has therefore become a promising candidate for resolving the issues of surface passivation on GaN.

To date, there has been little success in the development of native oxidation techniques on III–V nitrides. Direct oxidation of GaN in dry air has been investigated but reveals a slow oxidation rate of 20 nm/hr at 900°C.[2] There are, however, concerns regarding the high temperature treatment due to the surface degradation issues. In this work, we report a use of photo-chemistry to enable a *wet* oxidation process of GaN in phosphorus acid (H_3PO_4) solutions at room temperature. We thereby are able to reveal a reaction-rate limited oxidation process and observe enhancement in the PL and photo-current (PC) response on GaN for the first time. We attribute the latter to the surface passivation effects affiliated with a good thin film quality of gallium oxide formed on GaN.



CWB7 Fig. 1. SEM micrograph of photo-oxidized GaN samples with oxide layer thickness of (a) 100 nm and (b) 450 nm.

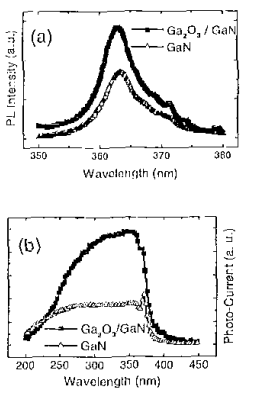


CWB7 Fig. 2. Time dependence of the photo-grown oxide at pH = 3.5. Inset shows the pH dependence of the normalized photo-oxidation rate in aqueous H_3PO_4 solutions.

The photo-chemistry process in GaN is that the ultraviolet (UV)-excited hot carriers at the GaN/electrolyte interface have excess energy to access the H^+/H_2 and OH^-/O_2 redox levels in water and enhance the oxidative dissolution of GaN.[3] In the experiments, the galvanic cell was formed by immersing a GaN working electrode and a platinum (Pt) counter electrode in the electrolyte and was illuminated with a 254 nm mercury line source of 10 mW/cm^2. The experiments were carried out in aqueous H_3PO_4 solutions at room temperature with *no* bias applied between the GaN sample and the Pt counter electrode.

Shown in Fig. 1 are the SEM micrographs of the oxidized GaN samples at pH = 3.5 with an oxide layer thickness of (a) 100 nm and (b) 450 nm, respectively. We note the thin-oxidized sample A has a purple-bluish color and reveals fine grain crystallites as shown in Fig. 1(a). A quantitative EDX analysis on the transparent-looking, mirror-like oxidized surface of sample B in Fig. 1(b) reveals a normalized atomic ratio of O: Ga = 58.85%:40.23% which suggests the composition of the oxide is likely to be Ga_2O_3. This is supported by a subsequent dissolution of the oxide layer in a 2 M potassium hydroxide (KOH) solution. Had gallium hydroxide formed in the oxidation process, it would be insoluble in the alkaline solution.[3]

Shown in Fig. 2 is the oxidation rate analysis of the photo-grown oxide in a H_3PO_4 electrolyte of pH = 3.5. The linear time dependence indicates a reaction-rate limited process has taken place, and the slope reveals a oxidation



CWB7 Fig. 3. The measured room temperature (a) PL, and (b) PC response from the as-grown and photo-oxidized GaN sample A.

rate of 224 nm/hr. We note the UV-assisted *wet* oxidation rate of GaN at room temperature is one order of magnitude higher than previously reported in the high temperature treatment.[2] Also shown in Fig. 2 is the pH dependence of the normalized UV-assisted *wet* oxidation rate of GaN in aqueous H_3PO_4 solutions. The observation of a peak reaction rate indicates a hydration action such that both of the solute (H_3PO_4) and the solvent (free water molecules) play an important role in the photo-oxidation process.[3] Finally shown in Fig. 3 are the (a) PL, and (b) PC response on the 100 nm oxidized GaN sample A and the as-grown GaN surfaces, respectively. Since the Fresnel loss due to the optical reflection at the GaN/air interface is no more than 20%, the threefold enhancement in the PL and PC optical response on the oxidized GaN samples are ascribed to an efficient surface passivation effect. This process will be valuable to the application of nitride-based opto-electronic devices.

In summary, we report a UV-enhanced, reaction-rate limited *wet* oxidation process on GaN at room temperature. A peak oxidation rate as high as 224 nm/hr can be achieved in aqueous H_3PO_4 solution at pH = 3.5. Enhancement in the PL and PC response from the oxidized GaN surface suggests an efficient surface passivation effect due to the photo-oxidation process on GaN.

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CWC 8:00 am–9:45 am
Room 102

Novel CPA Technology

Martin C. Richardson, *Univ. of Central Florida, USA, Presider*

CWC1 8:00 am

Optical parametric chirped pulse amplification

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Optical parametric amplifiers already have widespread use in applications requiring pulses with broad tunability and/or short pulse duration. However a new scheme[1,2] known as optical parametric chirped pulse amplification (OPCPA) because it uses an optical parametric amplifier (OPA) as a chirped pulse amplifier (CPA), offers further exciting possibilities for the generation of greatly increased pulse power and focused intensity.

A key feature of the CPA technique in this context is the ability to use narrow bandwidth (and hence long duration) pump pulses, which can be obtained from a variety of existing lasers. The OPCPA allows efficient transfer of energy from a narrow to a broad bandwidth pulse which is subsequently compressed to realise a large increase in pulse power.

The properties of the OPCPA are well suited to this technique. Gain bandwidths well in excess of those of conventional amplifiers are possible[3-5] and can lead to sub-5 fs pulses. High energy is available using large non-linear crystals such as KDP, which can be grown to sizes capable of being used with energies of several hundred joules. A CPA system must minimise the residual spectral (or temporal) phase. In an OPCPA this phase can arise from the optical parametric process and from the more usual effects due to GVD and B-integral. Theory and modeling show that the phase due to the intrinsic process does not pose a serious limitation. In addition, because the OPA can be operated at very high gain coefficient, the path lengths are short (for example 7 cm for a gain of 10^{11}) and lead to only small amounts of GVD and B-integral. The small path lengths and an almost complete absence of thermal effects also lead to high optical quality of the amplified beam, and this is maintained even in the presence of pump beam aberrations.

Designs using Nd:glass, Iodine and Nd:YAG pump lasers show promising possibilities. Highest powers of 10 PW and intensities of 10^{23} W/cm^2 are predicted using a Nd:glass laser. For an iodine laser a peak power of 4 PW and a power enhancement of 1000 are projected, while in a more modest but widely applicable arrangement the "regenerative amplifier replacement" offers enhanced bandwidth, better contrast and greater simplicity.

The latter is being implemented within a large Nd:glass CPA system and preliminary results are promising.[6] An intermediate energy scheme, designed to check much of the physics required for operating at the 100 J level, was tested and gave good agreement with the modelling. This scheme amplified 0.1 nJ chirped pulses to a fully saturated level of 0.5 J and recompressed them to 300 fs.

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CWC2 8:30 am

Optical parametric amplification of broadband chirped pulses at 1 micron

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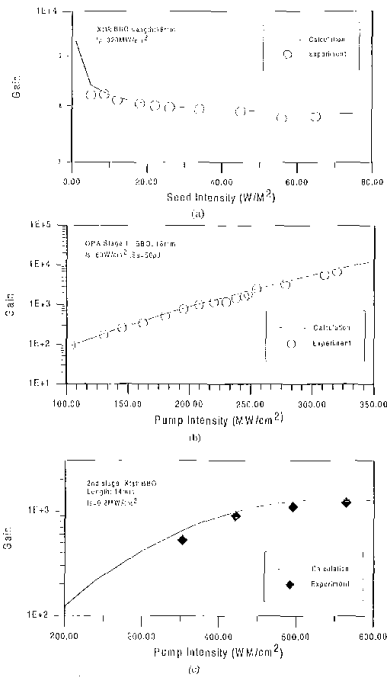
In the past few years, people recognized it is possible to amplify broadband optical pulses through optical parametric process with a few of well-developed nonlinear crystals. However direct amplification of the femtosecond pulses is limited by their pulse duration and associated nonlinear effects. We present here both simulation and experimental studies on a stable high gain OPCPA (optical parametric chirped-pulse amplification)[1,2] system which may be used as a preamplifier to replace the current complicated regenerative system and multi-pass Ti:sapphire amplifiers especially working at 1 μm.

Since the previous analytical analysis[2] doesn't apply in case of pump depletion, a program was especially developed to simulate the OPCPA process, including pulse temporal and spectral characteristics. This program played an indispensable role in our study and yielded consistent results with experiments, as shown in following figures.

The experimental setup consists of a stable diode-pumped Nd:glass femtosecond laser, grating stretcher, pump laser and a double-stage OPA. Femtosecond pulses are temporally



CWC2 Fig. 1. (a) OPCPA Gain dependence upon (a) input signal intensity; (b) pump intensity; and (c) double stage OPCPA gain dependence upon pump intensity. Curves are simulations, circles and diamonds are experimental data. Is: input signal intensity, Ip: pump intensity, Es: input signal energy.