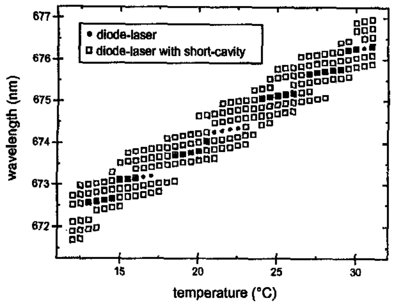

CTuM32 Fig. 2. Single-mode tuning characteristics of a standard diode laser (Hitachi HL 6720G) without an external cavity (black dots) and with a piezo-driven external cavity (squares).

μm by proper setting the temperature of the diode lasers and the one of the nonlinear crystal. The MIR laser power is typically $P_{DFG} = 0.2$ μW. Details of the laser system are described in Ref. 1.

The use of diode lasers as signal and pump sources for the DFG process limits the tuning range of accessible wavelengths in the MIR. There are several wavelengths within the gain profile of a diode laser, for which a single-mode operation is not possible. The black dots in Fig. 2 indicate the wavelength ranges for single-mode operation of a standard diode laser (Hitachi HL 6720G). Unfortunately, this characteristic mode jump behavior is different for each diode laser. However, the tuning characteristics of diode lasers can be improved very easily when an external short cavity around the laser is used.[2] In that case a glass plate is mounted on a piezo and is fixed close to the diode laser output (d<100 μm) to form an external cavity. By changing the reflectivity of the glass plate and the external-cavity length when applying different piezo voltages, the mode structure of the diode laser is modified. Results of such measurements are shown in Fig. 2 (squares). In that case all wavelengths in the spectral range between 672 and 677 nm are covered by single-mode operation. This improves the tuning characteristics of a MIR-DFG diode laser system significantly. First results of extended tuning possibilities in the MIR are reported.

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CTuM33

Deep ultraviolet enhanced wet chemical oxidation and etching of gallium nitride

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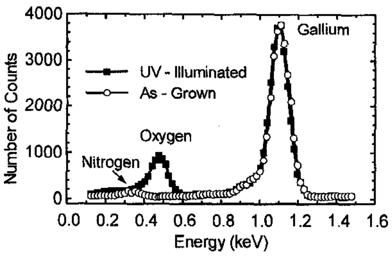
Etching of III-V nitrides has become an important processing technique for realizing short-wavelength emitters, detectors, and high-temperature electronic devices. Due to the chemical stability of III-V nitrides, current practice has instead pursued the dry-etching techniques. However, great challenges remain to reduce surface damage and increase layer selectivity in the plasma dry etching and to increase the etch rate in excimer-assisted dry etching. Ultraviolet (UV)-assisted photochemical wet etching of nitrides,[1] on the other hand, presents a promising alternative to solve these problems. In this work, we present a use of deep UV irradiation to enhance the oxidative-dissolution process in the photoelectrochemical (PEC) etching of gallium nitride (GaN). Our study indicates that the hydration effect plays an important role in establishing a peak etch rate as high as 90 nm/min. and 120 nm/min. in aqueous potassium hydroxide (KOH) and phosphorus acid (H_3PO_4) solutions at pH = 14.25 and 0.75, respectively.

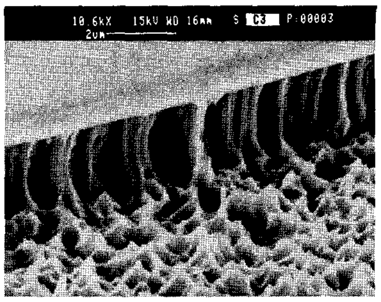


CTuM33 Fig. 1. EDX analysis of the as-grown and the UV-illuminated GaN samples.

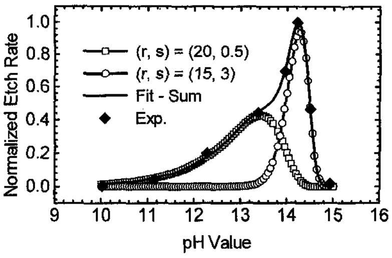
The unintentionally doped MOCVD grown GaN samples were measured to be *n* type with a carrier concentration of 10^{17} cm^{-3} and a thickness of 4 μm. To facilitate the PEC etching, a 253.7-nm Hg line source emitting at an intensity of 10 mW/cm^2 was used. The galvanic PEC cell was constructed by immersing a GaN working electrode, a Pt counter electrode, and a saturated KCl calomel reference electrode in the electrolyte. The PEC etching experiments were conducted at room temperature without external bias.

In Fig. 1 we compare the energy-dispersion x-ray analysis (EDX) data of the as-grown GaN sample with that under a UV-illumination in a dilute H_3PO_4 electrolyte of pH = 3. The dramatic increase of oxygen counts in the latter clearly indicates a rich oxide content. From an x-ray diffraction (XRD) analysis we identify the peaks at 2θ = 34.46° and 72.74° to the diffraction from β-Ga_2O_3 (111) and (222), respectively. The observation of UV-enhanced oxidation of GaN elucidates a promising consequence for wet chemical etching of GaN. In Fig. 2 we show the SEM micrography of a PEC etched GaN sample with a total etch depth ~2 μm. The vertical striations shown in the side-wall are due to the striations in the metal mask that were transferred into the GaN feature during the etch. With optimization of the masking process, the anisotropic PEC etching on GaN can yield smooth side-walls and enable etched laser facets.

We illustrate in Fig. 3 the pH dependence of the normalized GaN PEC etch rate in aqueous KOH solutions. A hydration model analysis of $R = C \cdot [H_2O]_f^r[OH^-]^s$ indicates the peaking effect is due to a competition between the free water molecules $(H_2O)_f$ and the hydroxyl ions (OH^-). In order to characterize the rapid variation of GaN etch rate at pH > 14 and the slowly falling tail in the dilute pH regime, two independent sets of exponents (*r*, *s*) = (15, 3) and (20, 0.5), respectively, are used in the analysis. These two sets of fitting parameters enclose the subtleties of the rate-limiting mechanism and are subjected to further investigation.



CTuM33 Fig. 2. SEM micrography of a PEC etched GaN sample.



CTuM33 Fig. 3. A hydration analysis of the PEC etch rate. A mean hydration number $n_h = 5$ was used for KOH in the analysis.

In summary, we have demonstrated a deep UV-enhanced oxidation and etching process on GaN. A hydration model analysis on the KOH-based PEC etch rate indicates the peaking effect is due to a competition between the $(H_2O)_f$ and OH^-.

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CTuM34

Semiconductor material process with UV laser irradiation

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In this paper, we present our results of using UV laser for processing silicon and GaAs. The laser source is the fourth harmonic (266 nm) of a *Q*-switched Nd:YAG laser. This laser source is highly coherent so that interference fringe can be easily formed. We have used a