erated VUV radiation is shown in Fig. 1. It should be noted that the radiation in the spectral range from 112-124 nm has been generated by mixing the pump radiation with the tunable signal radiation in Argon whereas the radiation in the range below 110 nm results from mixing with the idler in krypton.

The differences of FWDFM in the case of two-photon resonant (Kr) and nearresonant (Ar) excitation will be discussed. Coherent two-photon excitation of Kr is shown experimentally.

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Absolute internal quantum efficiency of an InGaN/GaN quantum well

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Gallium Nitride materials and alloys are fast becoming important semiconductors as blue and UV light-emitters due to their wide band-gaps. Applications for highly efficient blue LEDs and UV lasers include large full-color flat panel displays and high-density optical data storage.¹ We report what we believe to be the first measurement of the absolute internal luminescence quantum efficiency of an InGaN/GaN single quantum well.

The absolute external luminescence efficiency is calibrated with respect to a



CThU1 Fig. 1 Cross section of the InGaN/GaN single quantum well.

perfect 100% Lambertian reflector. In addition, a correction factor must be used due to the difference between the PL and the pump wavelength. The final step is then to obtain the internal efficiency of the quantum well from the calibrated external efficiency. The cross section of the structure of the InGaN/GaN SQW is shown in Fig 1. We use the "photonic gas model," which requires that we model losses in the semiconductor due to reflections from the air-GaN interface, absorption in the cap layer and quantum well, and solid angle for the photon escape cone.² Measurements included both luminescence due to the band-to-band transitions and luminescence due to all transitions. Results indicate that the band-edge luminescence internal efficiency is as high as 27% and the luminescence internal efficiency for the full spectral range is as high as 31% for high intensity optical pumping.

In conclusion, we have developed a technique to make accurate measurements of absolute internal luminescence efficiencies for the GaN materials and allovs.

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CThU2 4:45 pm

Lateral, wet thermal oxidation of AlAsSb lattice-matched to InP

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Recent advances in wet thermal oxidation of AlGaAs compounds have led to dramatic improvements in the performance of InGaAs/AlGaAs vertical-cavity surface-emitting lasers (VCSELs) in the $\lambda < 1$ µm wavelength regime.¹ Structures grown on InP cannot benefit from this technology because AlGaAs is mismatched to InP. While InAlAs provides an Al-bearing material, which can be lattice matched to InP, its low Al mole fraction results in very slow oxidation requiring high temperatures.² The other Al-bearing material, which can be lattice matched to InP is AlAsSb, which has an Al mole fraction of 1.0. It is thus ex-tremely reactive and similarly to AlAs, oxidizes quite readily.

Several AlAsSb samples were grown by solid-source molecular beam epitaxy. Samples consisted of 1088 Å of $In_{0.53}Ga_{0.47}As$, followed by 2484 Å of AlAs_0.56Sb_0.44 capped by another 1088 Å layer of $In_{0.53}Ga_{0.47}As$, grown lattice matched to InP substrates heated to 520°C.

Several mesa stripes of widths varying from 2 μ m to 200 μ m were lithographically defined and dry-etched prior to the oxidation. Oxidation was accomplished in open tube furnace held at 350°C for 1 h or at 325°C for 15.5 h by bubbling N_2 through water heated to $85^{\circ}C$.

Figure 1 shows the cross-sectional scanning electron microscope images of partially and fully oxidized mesa. The bright layer above the oxidized AlAsSb corresponds to an interfacial Sb layer, which emerges out of the AlAsSb layer upon oxidation leaving behind Al_2O_3 . The oxidized regions of the stripe appear swollen compared to the unoxidized regions due to formation of the interfacial Sb layer, rather than swelling of the oxidized layer itself.

Figure 2 shows an un-normalized Auger depth profile for the sample after oxidation. Before oxidation there is no O present and the Sb signal is observed concurrently with Al. After oxidation a Sb spike is visible between the top In-GaAs cap and the oxidized AlAsSb layer, with no corresponding O spike, indicating that the Sb layer is not oxidized. Quantitative analysis of the Auger data, calibrated on a known Al_2O_3 standard, indicates that the oxidized layer is Al_2O_3 , with no Sb present.

Raman spectroscopic measurements, shown in Fig. 3, confirm the elemental nature of the Sb film, which segregated from the oxidized areas. Following oxidation, the Raman peaks (LO = 373 cm⁻¹) associated with the buried AlAsSb layer are completely attenued by conversion to Al₂O₃ and/or absorption by the interfacial Sb layer. This Sb layer is evidenced by the appearance of a strong peak at 155 cm⁻¹, which correlates with the A_{1g} peak of crystalline Sb at 150 cm^{-1.3}



CThU2 Fig. 1 Cross-sectional scanning electron micrograph of a partially (a) and fully (b) oxidized InGaAs/AlAsSb/InGaAs structure.



CThU2 Fig. 2 Auger concentration depth profiles of the InGaAs/AlAsSb/InGaAs layer structure after oxidation.