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MBE Growth and Properties of ZnO on Sapphire and SiC Substrates

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Recently, compliant substrate technologies have been demonstrated for Si:Ge and for II-VI alloy semiconductors. The basic idea behind this approach is to force the misfit dislocations associated with non-lattice-matched heteroepitaxy down into a very thin compliant layer rather than permitting the defects to propagate upwards into the epitaxial overlayer of interest. In this way, the material of interest can be grown with much lower dislocation density. A compliant substrate technology is expected to play an important role in the development of III-V nitride materials for which there are no native homoepitaxial substrates. A potential material for use in such a technology is ZnO. ZnO has a hexagonal crystal structure with lattice constants (c = 5.213 Å, a = 3.249 Å) and thermal expansion coefficients ($\Delta a/a = 4.74 \times 10^{-6}$ at 300 K; $\Delta a/a = 8.31 \times 10^{-6}$ at 300 K) comparable to those of the III-V nitrides. Its band gap at 300 K is 3.3 eV. Although ZnO is considerably softer than the III-V nitrides, it is one of the most tightly bound of the wide-band-gap II-VI materials. As a consequence, it has a very high melting point (1975 °C) and its surface is stable with respect to sublimation at temperatures up to at least 900 °C. However, high-quality bulk crystals of ZnO are not currently available. In addition, because of its high sublimation and melting temperatures, sputtering is currently the preferred technique to prepare ZnO films for use in transparent conductor applications. MBE growth of ZnO has never before been demonstrated.

At NCSU, we have developed a novel approach for growing ZnO by MBE. Our approach employs a standard Zn effusion cell and an MBE-compatible plasma source to convert molecular oxygen into atomic oxygen for growth of ZnO. Optical emission spectra taken while the oxygen plasma source is operating show strong emission lines at 777 and 845 nm. High-resolution scans show conclusively that the observed emission peaks are due to atomic oxygen, specifically $3p\ ^5P \rightarrow 3s\ ^5S^o$ transitions at 777.2, 777.4 and 777.5 nm and a $3p\ ^3P \rightarrow 3s\ ^3S^o$ transition at 844.6 nm. No evidence of molecular oxygen is present in the optical emission spectrum.

Epitaxial growth of ZnO has been achieved using both sapphire and SiC substrates. Substrate temperatures for growth of ZnO ranged from 300-900 °C. Growth rates of ≥ 0.2 μm/hr were easily obtained using the oxygen plasma source. For both types of substrates, 2D growth of ZnO was achieved, as manifested by streaky RHEED patterns during film growth. The ZnO films

Submitted for SSDM'95 Symposium V: Blue/Green Light Emitters and Related Materials Science appear specular and transparent to the eye. As deposited ZnO films are n-type. Hall measurements yield carrier concentrations of 2 x 10^{19} cm^{-3} and mobilities of 30 cm^2/V-s -- comparable to the best bulk ZnO. Photoluminescence at 295 K is dominated by edge emission at ~3.3 eV.

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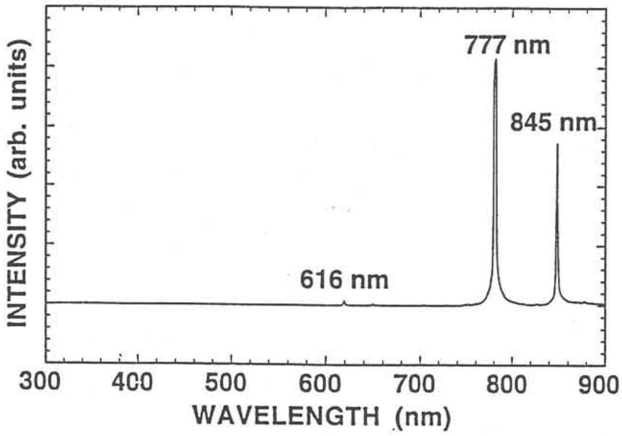

Figure 1. Optical emission spectrum from MBE-compatible oxygen rf plasma source. All observed emission peaks are associated with atomic oxygen.

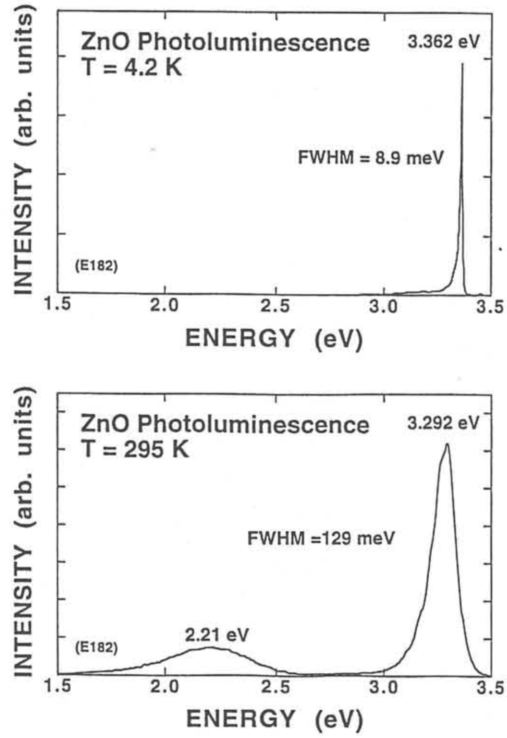

Figure 2. Photoluminescence of MBE-grown ZnO.