Pseudomorphic Al(Ga)N Semiconductors: From UVC LED and UVC LD to RF & Power Revolution

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High quality, two-inch diameter aluminum nitride (AlN) substrates are now available with dislocation densities below 10^5 cm^2 from several sources. These substrates are used in the commercial production of UVC LEDs in the wavelength range from 230nm to 280nm. These c-face aluminum nitride substrates are attractive for making short wavelength UVC LEDs because the low defect density in the substrate, combined with pseudomorphic epitaxial growth on the Al-polarity face, enables high Al-content Al(Ga)N device layers with similarly low threading dislocation densities. The advantages of the pseudomorphic Al(Ga)N/AlN technology appears to continue to increase at shorter wavelengths. Recently, the team at Crystal IS and Asahi Kasei have been able to achieve record high performance UVC LEDs on AlN substrates in the 230 to 240nm range. Low contact resistance and high conductivity were achieved in high Al concentration Al(Ga)N which enabled the low forward voltages (less than 6 V at 20mA) even though Al-mole fractions exceeded 83% in the well barrier, electron blocking layer, and Si-doped electron injection layer. At a 100mA drive current, the output powers were 2.2mW and 1.2mW at wavelengths 237nm and 230nm, respectively. These short wavelength LEDs have several interesting commercial applications include the monitoring of nitrates in water, NO_x and SO_x in gas emissions, DNA purity analysis, and high-performance liquid chromatography (HLPC). More recently, we have started evaluating these LEDs for efficacy in virus disinfection with the potential that they are safer for human exposure than longer wavelength germicidal UVC.

The pseudomorphic Al(Ga)N/AlN ultrawide bandgap semiconductor platform also enables other unique opto-electronic and high-power electronic devices. Recently, the team from Asahi Kasei, U. Nagoya, and Crystal IS succeeded in making the first UVC laser diode using pseudomorphic Al(Ga)N. These LDs had a threshold current density of 25 kA/cm^{-2} at a voltage of 13.8V in spite of having a relatively thick p-side waveguide and cladding layer without any extrinsic dopant. This was accomplished by using distributed polarization doping on the p-side to aid with hole injection. Evaluation of pseudomorphic Al(Ga)N/AlN for power devices has been initiated at several laboratories and will be summarized here. A key issue that remains to be solved in this attractive ultrawide bandgap semiconductor system is the formation of point defects in high Al-concentration Al(Ga)N which may be unstable under high current operation.