Magnesium and Beryllium Doping During rf-plasma MBE Growth of GaN

T. H. Myers and A. J. Ptak
Physics Dept., West Virginia University, Morgantown, WV 26506
(304) 293-3422 x1469 - tmyers@wvu.edu

L. T. Romano, C. G.Van de Walle, J. E. Northrup, M. Kneissl and N. M. Johnson
Xerox Palo Alto Research Center, Palo Alto, CA 94304

While magnesium is currently the most technologically important p-type dopant for GaN, Be also shows promise. Although Mg, and to some extent Be, have been extensive studied in the last several years, incorporation mechanisms during growth by molecular beam epitaxy (MBE) remain unclear. For example, previous studies have presented results that indicate Mg incorporation is independent of Mg flux over a wide flux range but is quite sensitive to substrate temperature, [1] and there is evidence for significant surface accumulation of Mg. [2] Two competing models have been put forth to explain much of the observed behavior. The first assumes the presence of a surface accumulation layer, with dopant incorporation linked to surface accumulation with incorporation driven by segregation effects. The second model assumes the presence of a finite concentration of sites on the growing surface where the Mg is strongly incorporated.

We present the results of a study of both Mg and Be incorporation for both N- and Ga-polarity GaN that strongly indicates surface accumulation occurs for both dopants under Ga-rich growth conditions. Indeed, many of the doping profiles we obtained strongly resemble classic cases of Sn segregation in GaAs or Sb segregation in Si growth. Figure 1 shows such a doping profile for Be incorporation. The exposure times of the growing surface to Be through shuttering are shown schematically in the figure. Figure 2 shows similar effects for Mg incorporation. In addition, we observe a significant difference in Mg incorporation between the two polarities, with Mg incorporating at a rate up to 20 times higher for Ga-polarity surfaces. There is less of an effect for Be, with a larger incorporation on the N-polarity. The phenomenon of polarity inversion linked to Mg on the growing surface was observed with transmission electron microscopy, and dramatically illustrates the lower incorporation rate that occurs for the N-polarity surface. An additional result of significance is that the presence of atomic hydrogen significantly alters the incorporation kinetics of both Mg and Be, decreasing segregation effects while maintaining or increasing the actual incorporation rate.

Results for Be doping experiments will also be presented. Preliminary measurements indicate that Be is a p-type dopant in GaN with an activation energy less than 100 meV, but as-grown samples appear to be heavily compensated. Be interstitials are one highly probable source of the compensation and attempts to control interstitial incorporation will be discussed.

This work was supported at WVU by ONR Grant N00014-96-1-1008 and at WVU and Xerox-PARC by ONR Contract N00014-99-C-0161, both monitored by Colin E. C. Wood.

---

[1] S. Guha, N. A. Bojarczuk and F. Cardone, Appl. Phys. Lett. 71, 1685 (1997).
[2] T. S. Cheng, S. V. Novikov, C. T. Foxon and J. W. Orton, Solid State Comm. 109, 439 (1999).

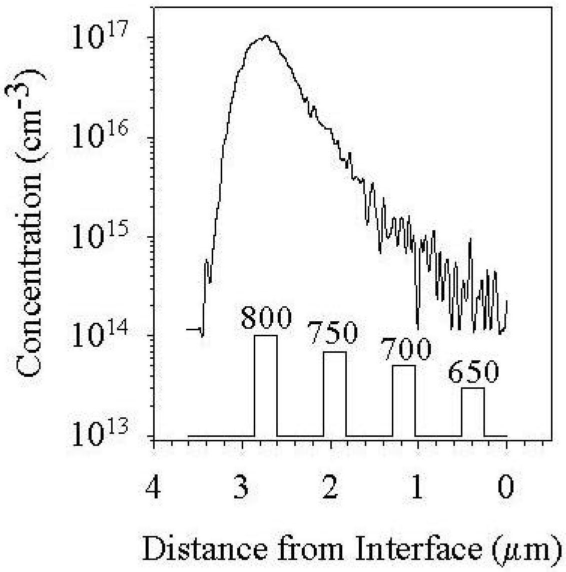

Figure 1. Be incorporation into Ga-polarity GaN grown by rf plasma MBE at 675°C for various Be oven temperatures, which are indicated schematically along with exposure times to the Be flux.

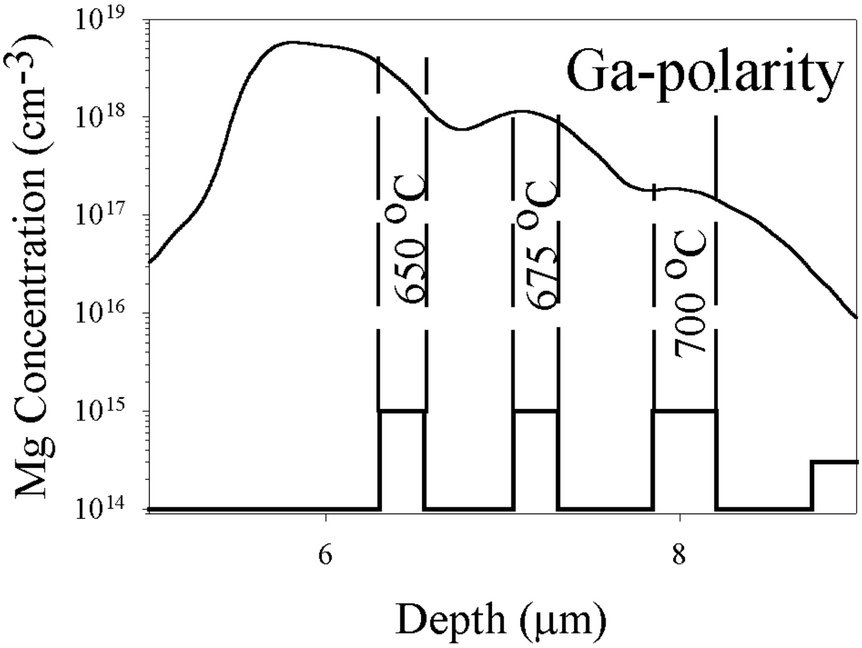

Figure 2. Mg incorporation into Ga-polarity GaN grown by rf plasma MBE at the indicated substrate temperatures. The Mg oven temperature was constant at 300 °C. Shutter operation is shown schematically to indicate exposure times to the Mg flux.