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Ferromagnetism in Transition Metal Doped GaN and Related Materials

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There is high current interest in the development of dilute magnetic semiconductor (DMS) materials exhibiting ferromagnetic behavior for spin-based light-emitting diodes, sensors, and transistors. Such materials are formed through the introduction of transition metal (TM) ions, such as Mn and Cr, into semiconductor hosts. Unfortunately many DMS materials, such as GaMnAs, have a relatively low magnetic ordering temperature (170 K for GaMnAs), which severely limits their usefulness. In the past few years, several groups have reported achieving ferromagnetism at room temperature in wide bandgap materials, such as GaMnN. This property makes these materials attractive for use as ultra-low-power switching elements, where the bit state of the device is determined through control of electron spin. Furthermore, these materials may also allow for the integration of photonic (laser and light-emitting diodes), electronic (field-effect and bipolar transistors) and magnetic (information storage) devices on a single substrate, leading to a new class of electronic devices that offer multi-purpose functionality. However, to realize such devices, several challenges remain. One concern to date has been the relatively low thermal stability of the III-Mn-N compounds. Doping with Cr in place of Mn, however, appears to greatly enhance the ability of the material to retain its magnetic properties even after annealing at temperatures up to 700C, easing the road to practical device fabrication. In addition, the ability to achieve magnetic behavior in a semi-insulating barrier material such as AlCrN opens new device possibilities. The most evident application of ferromagnetic AlN is as a ferromagnetic tunnel barrier, similar to EuS, but unlike EuS should allow for operation at room temperature. Growth of tunnel devices using Al-TM-N as a barrier and Ga-TM-N as a spin injector will be discussed. This work is supported by the Army Research Office under ARO-DAAD19-01-0-0701 and NSF under ECS-0224203.