Dilute Magnetic Contact for a Spin GaN HEMT

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Semiconductor CMOS nano-electronics is intensively seeking solutions for future digital applications. One of the most promising solutions to deliver a technological breakthrough is exploring electron spin in metals and semiconductors with applications from spin transistors to quantum sensors, and quantum computing [1]. Spintronic applications rely on magnetic semiconductor materials with suitable properties [2]. In particular, dilute magnetic semiconductors (DMS), such as Mn doped GaN, show the great promise of a high Curie temperature (220K–370K), exceeding room temperature, and a large concentration of holes. These are all the essential pre-requisites for operation of spin transistors (see Fig. 1) in circuits.

In this work, we dope an AlGaN/GaN heterostructure consisting of a GaN (2 nm) cap layer, an $Al_0.25Ga_0.75N$ (25 nm) barrier, and a GaN (2 μm) substrate grown on a 6″ Si wafer with Mn by sputtering deposition and thermal annealing to create a dilute magnetic semiconductor material following the process flow depicted in Fig. 3. While initial attempts resulted in the formation of a MnO surface layer [3], the SEM/XDS and XPS data in Figs. 4 and 5, respectively, suggest a diffusion of Mn into the GaN layer using thermal annealing at 900°C for 7h with a concentration of 4.5% which is very close to the desired concentration of 5% needed for a DMS. The annealing temperature has to be below 1000°C since temperatures around 1000°C result in significant damage to the 2DEG and diffusion of Al from the AlGaN layer.

References:[1] J. Fabian et al., *Acta Phys. Slovaca* **57**, 565-907 (2007). [2] T. Dietl and H. Ohno, *Rev. Mod. Phys.* **86**, 187-251 (2014). [3] F. C. Langbein et al., Cardiff Materials Net. Conf., Chepstow, UK, 17-18 Jan (2019).

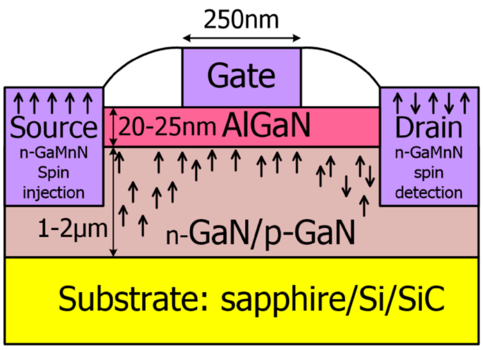

Fig. 1. Cross-section of spin GaN HEMT based on DMS spin injection contacts.

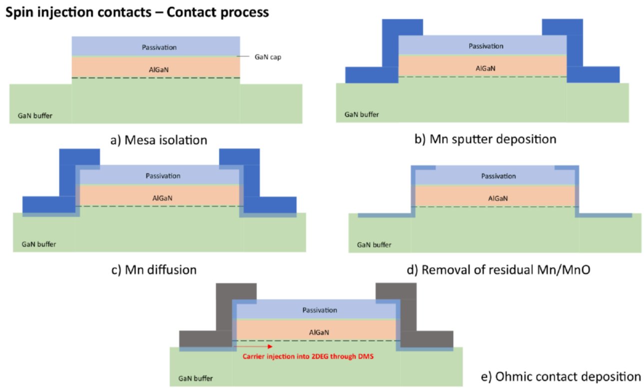

Fig. 2. Envisaged fabrication of ferromagnetic contacts on AlGaN/GaN heterostructure for spin injection to the channel at the AlGaN/GaN interface.

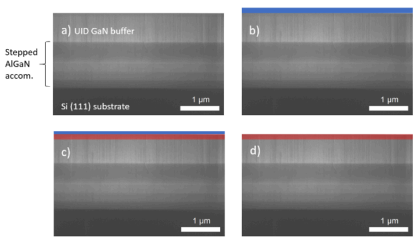

Fig. 3. a) SEM cross-section of UID GaN on Si showing stepped AlGaN accommodation layers. The diffusion doping process is shown schematically: (b) sputter deposition of Mn layer (c) annealing to diffuse Mn and create DMS region (d) removal of metallic Mn using HCl to expose DMS.

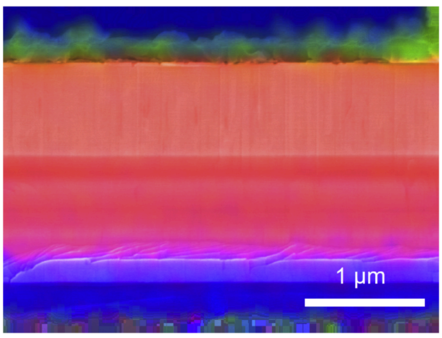

Fig. 4. Cross-sectional SEM/EDX map of Ga (red), Al (blue) and Mn (green) following annealing of Mn (Fig. 3c) at 900°C for 7h. Epi-layers are observed to still be intact with no major surface diffusion of Al from accommodation layers. Al at top of image is from background sample holder.

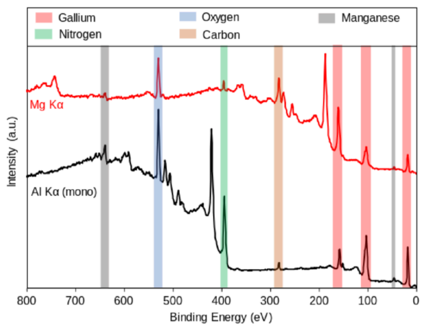

Fig. 5. XPS survey scans of MnGaN DMS after removal of metallic Mn (Fig. 3d)) following annealing at 900°C for 7h. Scans were produced using both Al Kα and Mg Kα, to allow separation of the Auger and core level photoelectron peaks. Mn concentration was found to be approximately 4.5%, ignoring adventitious carbon.