Low Contact Resistance Non-Alloyed Contacts to (010) β-Ga_2O_3 for kV Radio Frequency Applications

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Primary CNF Tools Used: ABM Contact Aligner, SC4500 Odd-Hour E-Beam Evaporator, Angstrom E-Beam Evaporator, RTA-AG610a, Glen 1000 Resist Strip, SAMCO UV-1 UV/Ozone, PT770, AJA Sputter Deposition

Abstract:

We demonstrate non-alloyed Ti/Au contacts to n+ (010) β-Ga_2O_3 doped by both *in-situ* doping during metal oxide chemical vapor deposition (MOCVD) and sub-oxide molecular beam epitaxy (MBE) with dopant concentrations well above 1×10^{19} cm^{-3}. The resulting contacts have sufficiently low (much less than 1 Ω-mm) contact resistance (R_c) even without alloying of the contacts.

Summary of Research:

Gallium(III) oxide (β-Ga_2O_3) has attracted interest in recent decades as a promising material candidate for kV radio frequency (RF) applications, especially in extreme environments, due to its large bandgap and critical electric field, decent carrier mobility, and availability of native substrates via melt-growth techniques. In order to enable high speed device applications, the parasitic resistance originating from the contacts should be much less than 1 Ω-mm. However, the low electron affinity associate with the wide bandgap leads to a lack of sufficiently low work-function metals to form ohmic metal-semiconductor junctions. Instead, ohmic contacts to Ga_2O_3 rely on tunnel junctions between a metal and heavily doped semiconductor region. However, the reliable formation of such junctions is non-trivial.

Previously, alloyed Ti/Au ohmic contacts were successfully formed to unintentionally doped (UID) epitaxy on semi-insulation Fe-doped (010) ion implanted with Si to a 100 nm box concentration of 5×10^{19} cm^{-3} by electron-beam evaporation and liftoff, resulting in an R_c of 0.16 Ω-mm. However, contacts formed by an identical process to MOCVD-grown Ga_2O_3 *in-situ* doped with Si to a concentration of 1.3×10^{20} cm^{-3} displayed highly rectifying behavior prior to alloying. While the contacts appeared ohmic post-alloying, the resultant contacts were spatially non-uniform, preventing extraction of R_c. We currently ascribe the abnormal behavior of these contacts to formation of a spatially non-uniform interfacial layer on the Ga_2O_3 surface.

In this work, a 102.5 nm UID buffer layer followed by 222.5 nm of Si-doped layer was grown on semi-insulating Fe-doped (010) β-Ga_2O_3 substrate via MOCVD. Room-temperature Hall measurements with In-dot contacts showed a free carrier concentration of 5.3×10^{19} cm^{-3} and a sheet resistance (R_{sh}) of 52 Ω/□. Transfer length method (TLM) patterns were fabricated using RIE for mesa isolation followed by non-alloyed Ti/Au (50/110 nm) contacts deposited by e-beam evaporation and patterned via liftoff. The as-deposited contacts were highly rectifying and spatially non-uniform.

The existing contacts were removed and Ti/Au ohmic contacts were re-deposited to form the device structure shown in Figure 1. Specific process details are anticipated for publication in the future. The resulting contacts demonstrate highly-leaky Schottky behavior, as seen in Figure 2a. At an applied current bias of 25 mA, the TLM patterns have an R_c of 0.49 Ω-mm without alloying as seen in Figure 2b.

Following this result, a 1 μm Si-doped layer was grown on semi-insulating Fe-doped (010) β-Ga_2O_3 substrate via suboxide MBE. Room-temperature Hall measurements with In-dot contacts showed a sheet resistance (R_{sh}) of 34 Ω/□. The carrier concentration was measured by secondary ion mass spectroscopy to be 2.99×10^{19} cm^{-3}. Non-alloyed Ti/Au (10/110 nm) were deposited by e-beam evaporation and patterned to form circular TLM (CTLM) patterns using a similar process to the non-alloyed MOCVD contacts. The device structure is shown in Figure 3. The resulting contacts are again highly-leaky Schottky in character, as shown in Figure 4a. At an applied current bias of 25 mA, the CTLM patterns have an R_c of 1.0 Ω-mm as show in Figure 4b, likely due to the lower doping level which naturally results in a thicker tunneling barrier and higher metal-semiconductor contact resistance.

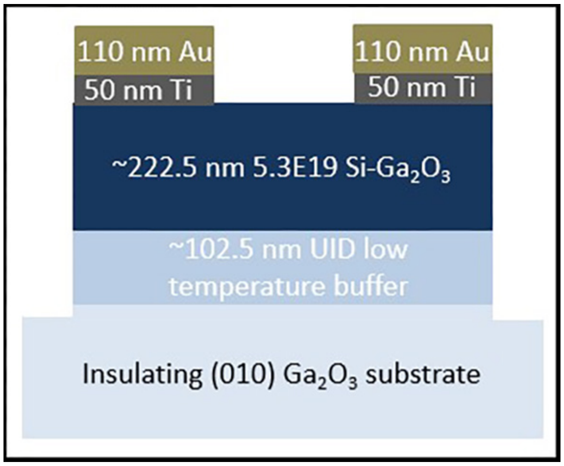

Figure 1: Device structure of the MOCVD-grown sample.

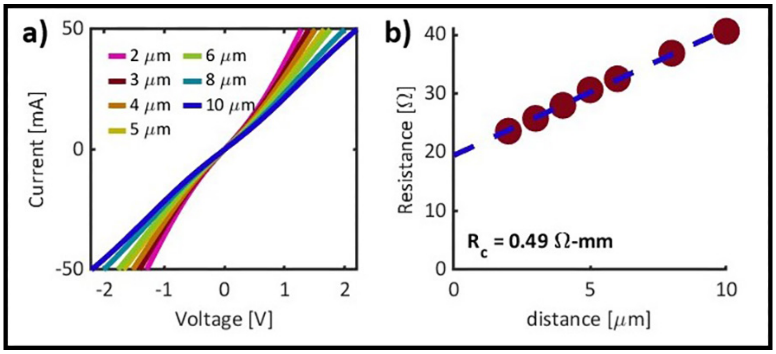

Figure 2: a) IV measurements of non-alloyed contacts display super-leaky Schottky behavior. b) TLM extraction of contact resistance at 25 mA applied current bias gives an R_c of 0.49 Ω-mm.

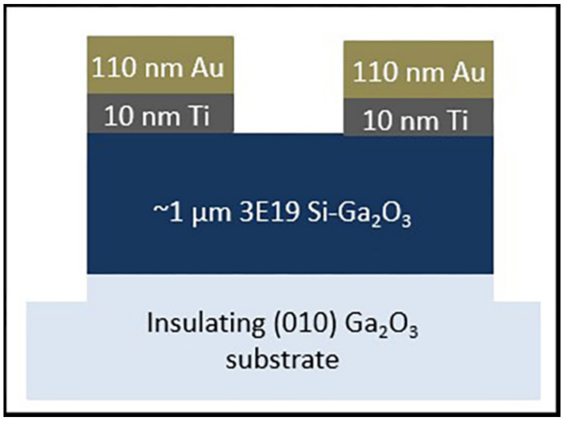

Figure 3: Device structure of the suboxide MBE-grown sample

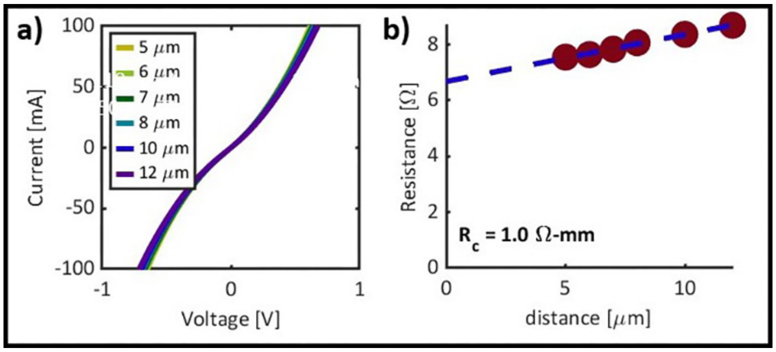

Figure 4: a) IV measurements of non-alloyed contacts display super-leaky Schottky behavior. b) TLM extraction of contact resistance at 25 mA applied current bias gives an R_c of 1.0 Ω-mm.

Conclusions and Future Steps:

In this work, we successfully demonstrate non-alloyed contacts on both MOCVD and suboxide MBE grown (010) n+ β-Ga_2O_3. Future work includes extensive characterization of the Ti/Ga_2O_3 interface to identify any interfacial layers that may have contributed to the non-uniformity observed in previous work and the initial MOCVD process. Further contact studies will extend to patterned regrowth of n+ β-Ga_2O_3 on n- doped epitaxy to investigate the resistance of the n+/n- semiconductor interface.

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