Finding the right balance for SnO growth enables the realization of all-oxide SnO/Ga_2O_3 vertical *pn* heterojunction diodes

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Oxide electronics is a rapidly developing field of research, yielding opportunities for transparent devices, solar-blind UV sensors, or energy-efficient power electronics. Currently, Ga_2O_3 is considered a champion semiconducting material for high-voltage power electronics that is predicted to outperform even GaN and SiC but can only be doped *n*-type. This doping asymmetry precludes the implementation of *p*-type functionalities based on Ga_2O_3, in particular technologically important *pn*-junctions which are building blocks for many types of devices. To make up for this shortcoming, we have prepared a *pn*-junction by combining the naturally *p*-type semiconducting oxide SnO with Ga_2O_3. The high hole mobility of SnO is beneficial for this and other applications but its growth is severely challenged by metastability with respect to the metallic Sn and the *n*-type semiconducting SnO_2.

Therefore, the growth of SnO by molecular beam epitaxy (MBE) requires a finely tuned balance of provided oxygen and Sn metal fluxes as well as a suitable growth temperature to prevent the formation of unwanted Sn or SnO_2. We solved this metastability problem [1] by applying a lesson previously learned from the MBE growth of SnO_2 [2]: The growth of SnO_2 proceeds in two reaction steps. In the first step SnO is formed from the Sn vapor and the oxygen. In the second step any oxygen that is left over can oxidize SnO further into SnO_2. This behavior can be followed in Fig. 1 (a) that shows the SnO_2 growth rate measured during growth with different amounts of supplied oxygen. At the oxygen flux of 0.15 sccm, marked with the green circle, growth of SnO_2 ceases and just enough oxygen is provided for the first reaction step that forms the SnO. In this fashion the sweet spot for SnO growth was rapidly found in a single experiment and used for subsequent growth of a *p*-type SnO layer on an *n*-type semiconducting Ga_2O_3 substrate at a lower growth temperature T_g of 400°C. Single-crystalline reference layers grown on insulating Y-stablized ZrO_2 showed non-degenerate, phonon-limited transport properties with room-temperature hole mobilities up to 6 cm^2/Vs and non-degenerate hole concentrations on the order of few 10^{18} cm^{-3}.[1]

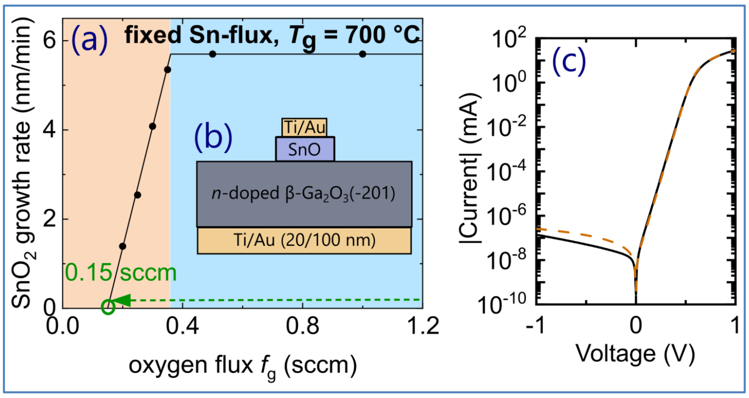

Figure 1: (a) Finding the right growth conditions for SnO based on in-situ measurements of the growth rate of SnO_2. (b) Schematics of the processed, vertical SnO/Ga_2O_3 pn-diode. (c) Current-voltage characteristics of the diode including fit (orange, broken line) to the diode equation. The inset indicates the low turn-on voltage.

After growth, the SnO/Ga_2O_3 sample was processed into a vertical diode, [3] whose structure is schematically shown in Fig. 1 (b), and current-voltage measurements were taken between the top and bottom Ti/Au-contact of this diode.

The results shown in Fig. 1 (c) reveal a diode-like characteristics with high rectification of 2 x 10^8 at +/-1 V and an ideality factor of 1.16, indicating a high-quality *pn*-junction. The related *pn*-junction isolation even prevented parallel conduction in the highly conductive Ga_2O_3 substrate during measurements of the electrical properties of the SnO layer on top, highlighting the potential for decoupling the *p*-type functionality in lateral transport devices made of SnO from that of the underlying *n*-type Ga_2O_3 substrate. In addition, the *pn* junctions may contribute to field management required to reach higher voltage capabilities in Ga_2O_3 devices.

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GraFox publications are highlighted by an "*".