Acceptor Characterization in Nickel Oxide for Ultra-wide Bandgap Multidimensional Power Devices

A major challenge in the design and fabrication of high voltage, high power devices using ultra-wide bandgap (UWBG) materials is the lack of shallow level, selective area p-type doping. Naturally, p-type wide bandgap (WBG) materials such as NiO offer a potential way to form conformal, area selective PN heterojunctions with UWBG materials. This work examines the modulation of the p-type doping level of magnetron sputtered p-NiO/n+Ga_2O_3 heterojunctions as a function of deposition conditions and effective film thickness. Doping level and acceptor characteristics are studied via capacitance characteristics of the devices as a function of voltage, frequency and temperature (CVf-T).

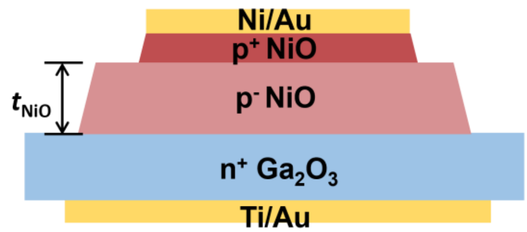

Fig.1. Structure of the p-NiO/n+Ga2O3 PN heterojunction diode fabricated for this work

Fig. 1 shows the structure of the NiO/n+Ga_2O_3 diodes fabricated to characterize the doping properties of NiO. The devices are fabricated via magnetron sputtering of a NiO film onto an n+ Ga_2O_3 substrate with variable O_2/Ar flow rates, followed by e-beam deposition of anode and cathode metallization and lift-off to define the device area. The magnitude of the p-type doping is found to vary between 9x10^{17} cm^{-3} for 0% O_2/Ar flow rate to 1.5x10^{18} cm^{-3} for 5% O_2/Ar. Fig. 2 shows the results of CVf-T measurements on the diode structure with a NiO film sputtered under 0% O_2/Ar flow rate. The presence of dispersion with multiple cut-off frequencies in the Cf-T characteristics of the device (Fig. 2(a)) beyond 1 kHz suggests that the acceptor state in NiO is a deep level with multiple charge transitions. Arrhenius fits to the dispersion cut-off frequencies give two acceptor activation energies of 0.35±0.03 and 0.54±0.08 eV. These values are close in range to theoretically predicted values for the (0/-1) and (-1/-2) charge transitions of the Ni vacancy (V_{Ni}) acceptor in NiO. Similar measurements in NiO sputtered with a 12.5% O_2/Ar flow rate show a single dispersion cutoff with an extracted acceptor energy of 0.35 eV.

In conclusion, this work demonstrates that the doping concentration of magnetron sputtered NiO can be modulated via O_2 flow rate. In addition, it is found that the V_{Ni} acceptor level is deep, at around 350 meV. These findings have implications for the use of sputtered NiO as a building block in switched power devices, as the deep V_{Ni} level may directly effect device switching speeds.

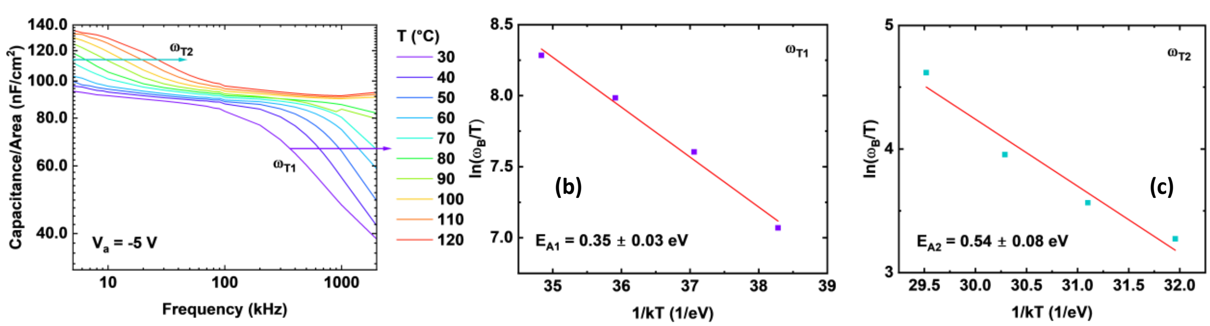

Fig. 2. Cf-T characteristics and Arrhenius analysis of the acceptor ionization energies in 0% O_2/Ar sputtered NiO. (a) Cf-T characteristics at -5 V reverse bias (30 to 120 C) (b) Arrhenius plot for extraction of first V_{Ni} ionization energy (c) Arrhenius plot for extraction of second V_{Ni} ionization energy