Transport behaviour of boron delta–doped diamond

J. Scharpf, E. Kohn, Universität Ulm, Germany
A. Bergmaier, S. Eschbaumer, G. Dollinger, LRT2, UniBw München, Germany

Two–dimensional (2D) conducting channels in diamond have gained considerable interest for high current/high power electronic applications. Due to its exceptional properties like chemical stability, high thermal conductivity and high electric breakdown strength, diamond is a favourable candidate for device concepts operating at high current densities and high temperatures.

The electrical transport properties of two–dimensional (2D) boron–doped delta layers were investigated by a comprehensive analysis of physical, electrochemical and microscopic methods. The boron concentration profile was determined physically by elastic recoil detection (ERD) and compared to the doping (acceptor) profile extracted from capacitance–voltage (CV) measurements, giving a boron concentration of $2-4\times10^{13}\mathrm{cm}^{-2}$. Corresponding field effect transistor (FET) characteristics, based on the boron–doped delta channel concept, measured in electrolyte, show good modulation behaviour but field effect mobilities in the range of $10^{-2}-10^{-1}\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$ that are far below expected values. High–resolution transmission electron microscopy (HR–TEM) analysis was employed to shed new light on the transport behaviour of boron–doped delta layers, revealing an inhomogeneous and interrupted morphology. Based on this finding, a hypothesis is proposed, modelling the delta layer transport behaviour via hopping and tunnelling processes between boron clusters [1].

The physical/chemical analysis by high resolution ERD [2] provides information about the total boron content in the diamond crystal. The measurements were done at the high resolutioh ERD setup at the Q3D magnetic spectrograph at the Munich tandem accelerator. The resolution limit for the boron detection was $2\times10^{11}\mathrm{cm}^{-2}$, corresponding to about $1\times10^{17}\mathrm{cm}^{-3}$ ($\approx 1\mathrm{ppm}$) boron concentration in diamond. Figure 1a shows the boron doping profile from the surface to a depth of 5 nm. Beyond a depth of 2.3 nm, no boron signal could be detected, corresponding to an upper limit for the boron concentration of approximately $1\times10^{17}\mathrm{cm}^{-3}$ in this region. This confirms a very sharp doping profile with a full width at half maximum (FWHM) of 1 nm, corresponding to about seven atomic layers at a diamond lattice constant of 0.35 nm. The peak boron doping concentration could be extracted to approximately $5\times10^{20}\mathrm{cm}^{-3}$, located at 1 nm depth. The gradient on both sides of the peak is about 0.9 nm per decade . Integrating the boron profile concentration over the entire depth and assuming that all boron is electrically active, this leads to a sheet charge carrier density of $4\times10^{13}\mathrm{cm}^{-2}$, being only slightly above the boundary conditions for delta–channel FET concepts, based on planar doping, as explained in the introduction of Ref. [1].

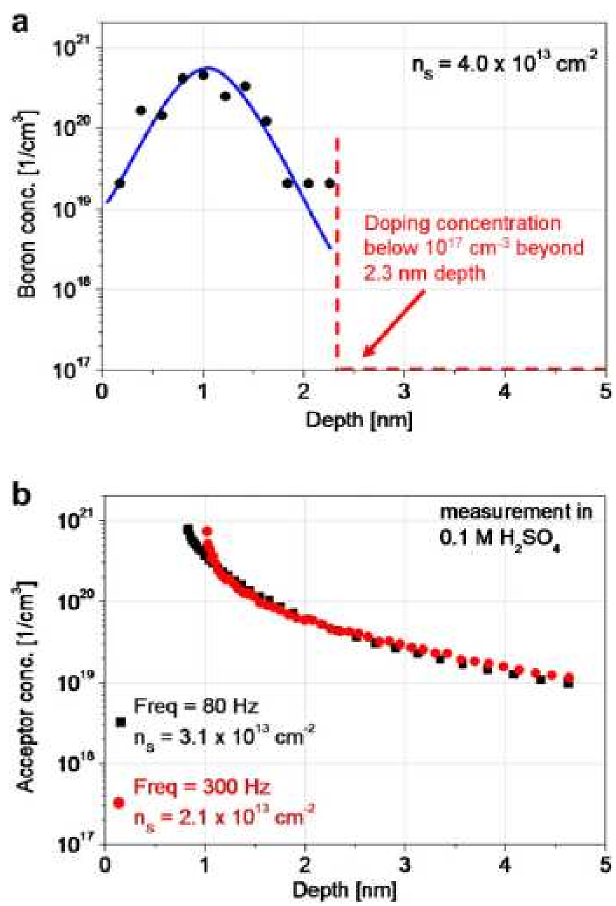

Figure 1: (a) High resolution ERD profile of a boron–doped delta layer on diamond. The FWHM is 1 nm. (b) Delta layer acceptor profile extracted from electrochemical CV analysis.

REFERENCES

[1] J. Scharpf et al., Phys. Status Solidi A 210, No. 10 (2013) 2028–2034.

[2] G. Dollinger et al., Nucl. Instrum. Methods B 219–220 (2004) 333.