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Diamond Electronics and Related Wideband Gap Semiconductors for High Temperature Applications

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This presentation is focused on understanding the basic science of two-dimensional carrier systems in diamond-based semiconductor electronics. Over the course of the presentation, we will present the following:

- Process technology for diamond power field effect transistors (FETs) based on two-dimensional (2D) carrier transport in subsurface boron delta-doped structures
- The theory of carrier transport in diamond FETs with 2D conducting channels
- The results from materials and defect characterization techniques to locate, characterize, and monitor radiation-induced defects in these structures over various timescales
- New research directions in applying 2D conduction channels to ultra-wide bandgap semiconductor transistors based on diamond materials as well as related wide band gap semiconductors,
- Understand the dominant failure mechanisms operative in diamond-based FETs exposed to ionizing and non-ionizing radiation.

Commercially supplied undoped (100) type IIa single crystal high pressure high temperature (HPHT) substrates were used in the UMD research. This type of substrates was selected because of their very low dislocation density, as dislocations could act as carrier scattering centers. To reduce the possibility of scattering further, these substrates were polished and etched with a low power plasma. To verify the effects of polishing and etching, RMS roughness value of less than 3 Å was determined using atomic force microscopy (AFM).

The substrate surface was exposed to a hydrogen plasma at temperatures above 700 °C to achieve hydrogen termination which leads to a negative electron affinity (NEA) surface. This NEA surface loses electron to atmospheric moisture and contaminants which act as surface transfer dopants, leaving behind a conductive two-dimensional hole gas (2DHG) near the surface.

A schematic of MOSFETs fabricated using HPHT hydrogen terminated substrates is shown in Fig. 1. A blanket Au layer of 100-150 nm was evaporated on the surface of the hydrogen terminated substrate. Device mesas were created using etchback process with KI/I_2 wet etchant. To isolate the devices, O_2 plasma etch was employed which replaced C-H bonds with C-O bonds between devices, effectively eliminating 2DHG channel underneath. KI/I_2 wet etchback was performed to form discrete Ohmic contacts from the Au mesas. 25 nm of Al_2O_3 was deposited by atomic layer deposition (ALD). Using e-beam and liftoff processes, 100 nm of Al gate was deposited.

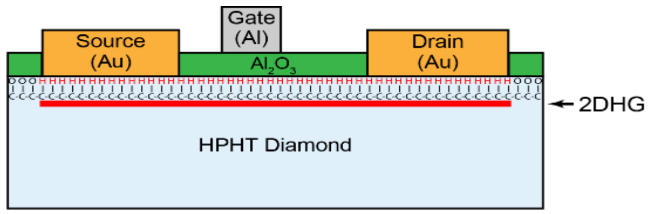
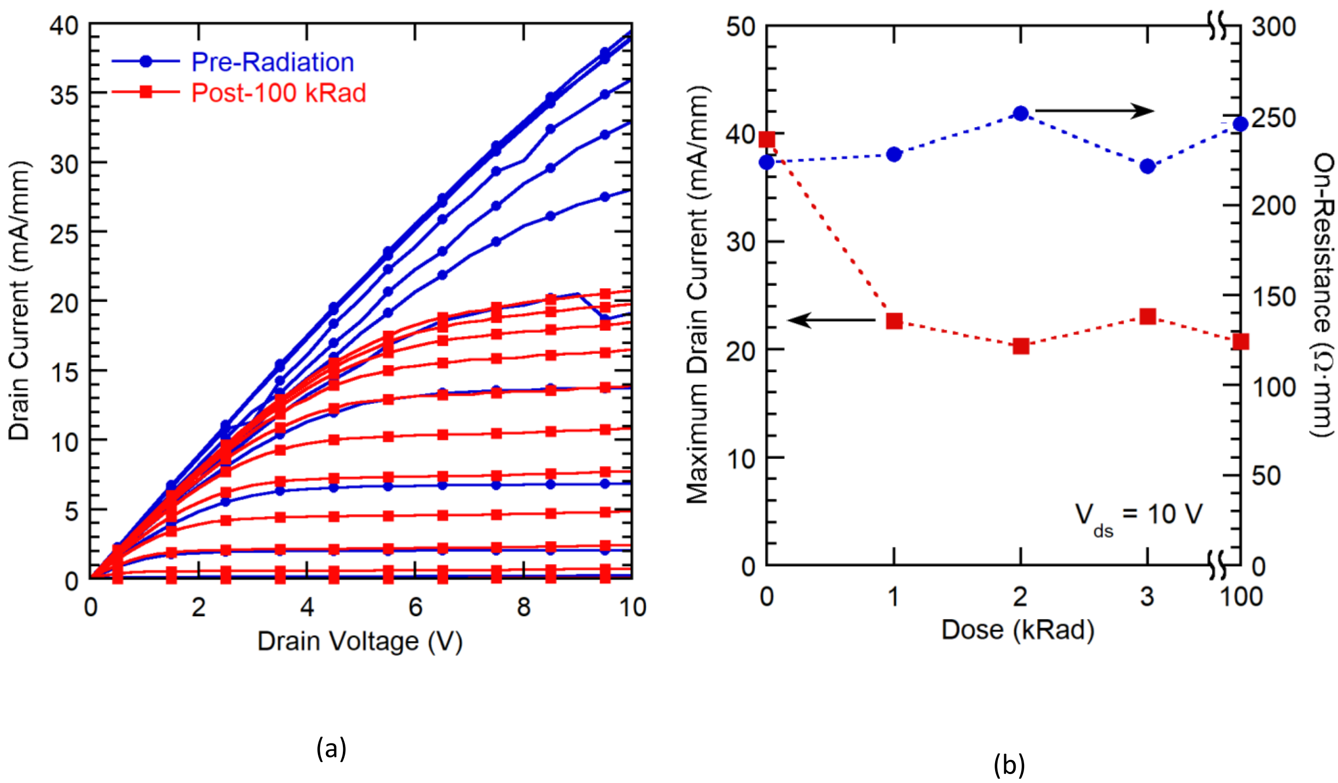


Fig. 1. Hydrogen-terminated diamond FET schematic with Al_2O_3 gate dielectric and surface transfer dopant.

These FETs were subject to gamma irradiation at the University of Maryland Radiation Facilities (UMRF) which used ^{60}Co panoramic source for gamma irradiation. The devices were subject to low dose gamma irradiations upto 100 kRad. Current-voltage measurements showed initial decrease in drain current, threshold voltage, and transconductance after 1 kRad dose. However, these parameters remained stable thereafter up to 100 kRad. Fig. 2 shows these results.



(a)

(b)

Fig. 2. (a) Drain current vs. gate voltage comparing pre-radiation and post 100 kRad dose of gamma irradiation (b) Maximum drain current and on-resistance as a function of radiation dose

This presentation also reports on our research efforts to explore devices based on double delta doped diamond substrates. Fig. 3 shows schematic of FET device on double delta doped

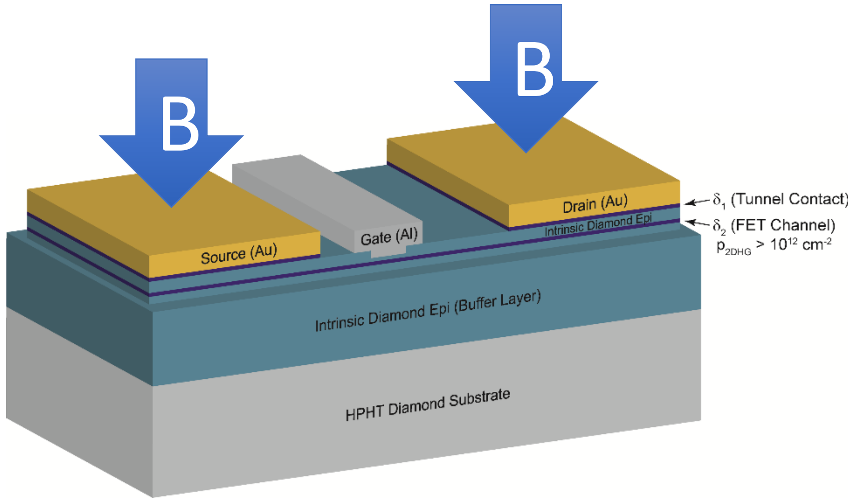


Fig. 3. Schematic of FET device on double delta doped substrate showing boron implantation underneath the contacts

structure. Diamond epi layer was grown on HPHT diamond substrate. At 26 nm from the top surface, boron doped layer of 1.85 nm thickness was incorporated in the epi with boron concentration of 1.20×10^{21} given by SIMS. This δ_2 layer is expected to form the FET channel. Similarly, another boron doped layer of about 0.75 nm thickness with boron concentration of 4.96×10^{20} was incorporated at the very top surface of the epilayer. This δ_1 layer is expected to aid in Ohmic contact formation. Furthermore, boron ions were implanted directly underneath the ohmic contact pads to aid in proper conduction from the contact metals through to the δ_2 layer. TRIM simulations were used to determine the concentration profile of dopant boron atoms at a given implantation energy and dose. After boron implantation step, Ti/Pt/Au of thicknesses 50/50/150 nm respectively were deposited as contact metals.

These devices had high transconductance behavior as well as thermal stability up to 450 degrees C. The electrical stability will be reported as well as the radiation hardness of these devices.