

1. FINAL PUBLISHABLE SUMMARY REPORT

Robust and high-sensitivity pressure sensors are strongly in demand in order to operate in harsh environments (high temperatures, corrosive chemicals, etc) such as in the hot section of a turbine engine. Conventional pressure sensors made from metal foils suffer from limited sensitivity, large temperature dependence, and high-power consumption. Piezoelectric materials alone can only be used under ac condition.

In order to perform pressure sensing at high temperatures, we propose a self-integrated metal-piezoelectric-insulator¹-semiconductor (MPIS) field-effect transistor (FET) device concept for high-sensitivity and high-temperature pressure detection based on microelectromechanical system (MEMS) technology. The MPIS-FET is fabricated on a robust semiconductor with freestanding or suspended structure.

To achieve the objective, we propose the application of diamond as the semiconductor and the structure material (cantilevers or bridges) for high temperature applications. The reasons to select diamond are: (i) diamond is the best semiconductor for high-temperature applications since it has a wide bandgap (5.5 eV), a high breakdown electric field, a high carrier mobility, and the highest thermal conductivity, and (ii) diamond is the ideal MEMS material due to its outstanding properties such as the highest Young's modulus, the highest hardness, a hydrophobic surface, low mass density, and high corrosion resistance upon caustic chemicals. On the other hand, high-Curie temperature ferroelectrics are required as the gate insulator on semiconductor. $\text{Bi}_x\text{Ti}_y\text{O}_z$ (BTO) has a high Curie temperature above 500 °C and also shows high ferroelectric polarization.

To fabricate the ultimate MPIS-FET, the interface properties between the gate oxide and the semiconductor should be understood and controlled. Due to the low bandgap of BTO, wide bandgap oxide such as Al_2O_3 is firstly selected as the gate oxide on diamond to reduce the leakage current of the MIPS-FET. The Al_2O_3 layer can also act as a buffer layer for BTO growth on diamond. We developed for the first time the impedance spectroscopy for the characterization the interface of the MOS structure based on p-type diamond. An Al_2O_3 layer was used as the gate oxide on diamond with a p-type channel due to surface hydrogenation. The advantage of the impedance spectroscopy (IS) over the normal capacitance-voltage technique is that the series resistance effect in the device and measurement system can be avoided, so that the origin of the frequency dispersion effect can be distinguished. Based on the IS data analysis with a combination of the C-V technique, the interface states of the MOS structure can also be understood. Therefore, a precise gate capacitance can be obtained in principle. By using the IS technique, we obtained a dielectric value close to 9, which was larger than that obtained by C-V method.

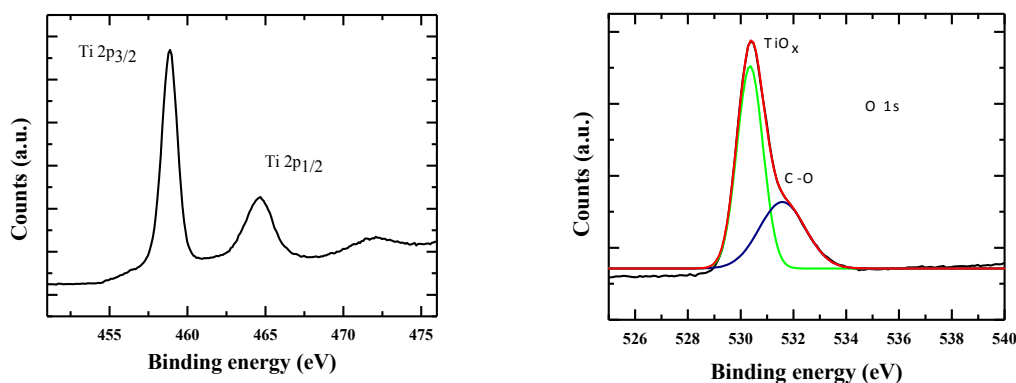


Fig.1 (a) XPS spectrum of Ti 2p in TiO_x ($x=1.8$), (b) XPS spectrum of O 1s in TiO_x ($x=1.8$)

¹ Sometimes insulator is used instead of oxide

In addition, we developed an energy-efficient low-temperature method for the fabrication of gate oxides with high dielectric constants on p-type diamond. As an example, we selected TiO_x with high dielectric constant as the initial candidate. As shown in Fig. 1 of X-ray photoemission spectroscopy (XPS), the metallic Ti with a thickness of 10 nm was fully oxidized at 110 °C in air. We used this TiO_x layer successfully for the fabrication of diamond MOSFET. Fig. 2 is the FET structure and properties of the MOSFET containing source, drain and gate. The transistor action was successfully demonstrated with good gate controlled drain current behaviour.

Furthermore we developed BTO thin film by using seeding layer of ZnO. It was observed that the ZnO layer led to the formation of ferroelectric BTO layer on silicon substrate. This ZnO layer is expected to be efficient for the formation ferroelectric BTO on diamond. On the other hand, diamond cantilevers fabricated by fs-laser radiation was fabricated for the first time in the world. In the future, the MOSFET will be fabricated on the free-standing diamond structure for pressure sensing.

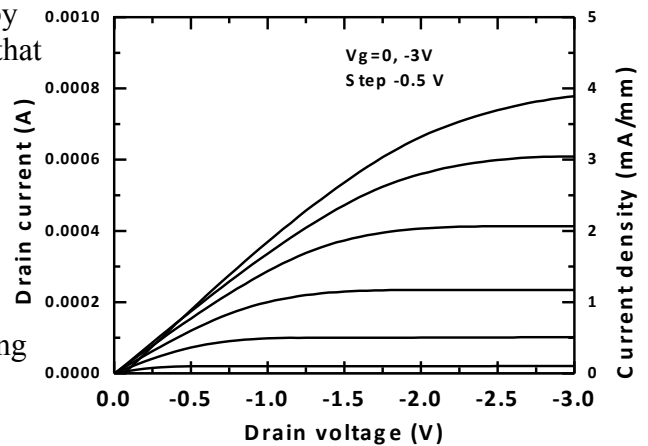
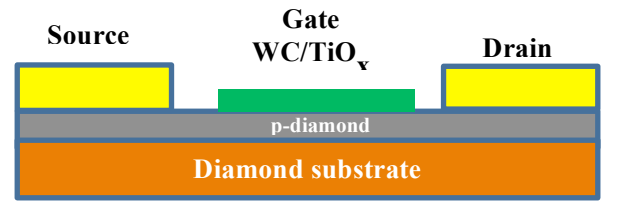


Fig. 2 Configuration and properties of MOSFET based on gate TiO_x and p-type diamond layer and

Pressure sensors, or pressure transducers, can find a variety of applications in automotive, aerospace, and industries. For example, in the field of automotive, pressure sensors can be used in aerodynamics, air bag systems, brake pressure, engine oil pressure, exhaust system testing, and fuel pressure etc, and in the field of aircraft, pressure sensors can be used to monitor the reaction control system. In addition, pressure sensors can be adapted to measure forces or structural vibration and act as electrical switch in cranes and earthmovers. In some cases, such as oil, gas and geo-thermal explorations and drilling, combustion process control in an engine cylinder or a gas turbine, the environmental temperatures are usually higher than 200°C, and the pressure sensors are often exposed to the ambient gas for real time monitoring. Such ambient consists of a variety of reactive gas such as oxygen, hydrogen or hydrocarbon in fuel, NO_x, and SO_x in the combustion products. These gases are chemically corrosive to the pressure sensors. This project should find applications in these fields.