Electrical Properties Suggest Potential for p-Type Conduction in r-GeO_2 Semiconductor
~ Planning to Verify p-Type Conductivity Through Multiple Evaluation Methods ~

Patentix Inc. has obtained results suggesting that hole-dominant electrical conduction occurs when acceptor impurities are doped into rutile-type germanium dioxide (r-GeO_2), a next-generation power semiconductor material, during film deposition. Although this is not yet definitive proof of p-type conduction, it represents a significant technological advancement. Moving forward, the company aims to conclusively demonstrate p-type conduction in r-GeO_2 by conducting polarity evaluations using multiple methods, focusing on electrical characterization.

Background

Rutile-type germanium dioxide (r-GeO_2) is a candidate for next-generation power semiconductor materials, possessing an ultra-wide bandgap (4.68 eV) that is even larger than that of silicon carbide (SiC) and gallium nitride (GaN). It has recently attracted significant attention due to theoretical predictions that it can achieve both p-type and n-type conductivity through impurity doping, which is difficult for other ultra-wide bandgap semiconductor materials.

Our company has previously reported the world's first successful demonstration of n-type conduction in r-GeO_2 by doping with antimony (Sb) as a donor impurity. However, p-type conduction had remained at the theoretical prediction stage, and experimentally proving it has been a critical challenge in the research and development of r-GeO_2.

Results

Using our proprietary film deposition technology, the Phantom SVD method, we have successfully fabricated an acceptor-doped r-GeO_2 thin film on a rutile-type titanium dioxide (r-TiO_2) (001) substrate and, for the first time in the world, succeeded in evaluating its electrical properties.
Figure 1 shows the appearance of the sample fabricated and evaluated in this study. Electrodes are formed on the acceptor-doped r-GeO_2 thin film to measure its electrical properties.

Figure 1. Sample for electrical property measurement of the acceptor-doped r-GeO_2 thin film

Capacitance-Voltage (C-V) measurements conducted using the formed electrodes showed a behavior where the measured capacitance decreased as the applied voltage was swept from negative to positive direction (Figure 2). This measurement result is believed to suggest that electrical conduction by holes is occurring in the acceptor-doped r-GeO_2 thin film, indicating the possibility of p-type conductivity.

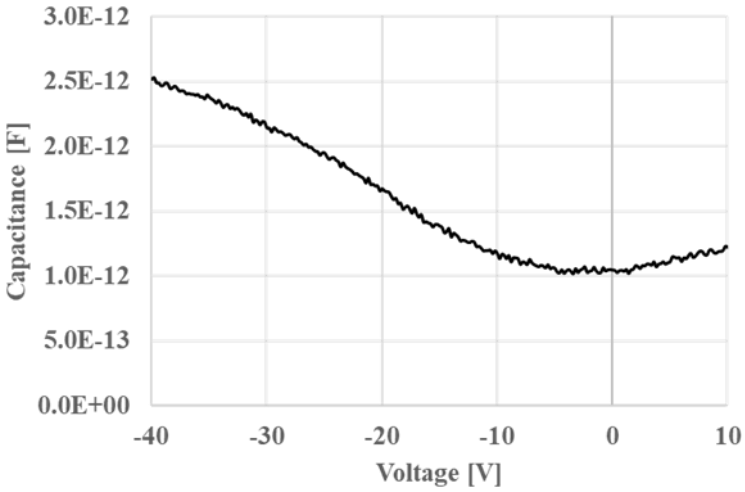

Figure 2. C-V characteristics of the fabricated sample

This achievement is crucial progress toward realizing r-GeO_2 as an ultra-wide bandgapsemiconductor capable of both p-type and n-type conduction. However, the experiments necessary to prove p-type conduction, such as measurement of hole

mobility and confirmation of rectification properties by forming a p-n junction, are yet to come. Most oxide semiconductors exhibit n-type conduction, with very few showing p-type conduction. Furthermore, achieving p-type conduction becomes more difficult as the bandgap increases. There is a history of many hasty reports about p-type conductivity in oxide semiconductors, which were later found to be incorrect. We believe that our current results alone are still insufficient to prove p-type conduction, and we will continue our research to demonstrate it through other evaluation methods, such as Hall effect measurements.

Future Outlook

This finding suggests the possibility of p-type conduction in r-GeO_2 and mark important progress toward the practical application of this next-generation power semiconductor material. We will continue our efforts to definitively prove p-type conduction. Specifically, we will determine the carrier type through Seebeck effect measurements and, most importantly, measure the hole mobility. Our challenge is to selectively create both p-type and n-type semiconductors with significant mobility through impurity doping, which has been difficult to achieve in oxide semiconductors. Furthermore, by forming a p-n junction, we will confirm its rectification properties and elucidate the physical properties of the p-type r-GeO_2 layer. These achievements are a vital foundation for the future development of mass-producible devices such as power MOSFETs and CMOS with r-GeO_2.