Potential of rutile-type GeO_2 with a huge band gap and ambipolar dopability

Kentaro Kaneko
Ritsumeikan University, Japan
E-mail: ken0710@fc.ritsumei.ac.jp

Semiconductors with a bandgap of 4 eV or more are called as a UWBG semiconductor, such as gallium oxide, diamond, aluminum nitride. It is gathering much attentions as a next-generation power semiconductor for their huge bandgaps and high break-down electric field. However, for the widely-spread on practical application, new power semiconductors are required to meet various conditions. It should possess a larger Baliga figure of merit than widely used materials of Si, SiC and GaN accompanying low-costs of substrates and films. Furthermore, possibility of p- and n- type carrier control, in other words, ambipolar dupability is also required for realization of normally-off MOSFETs. Rutile-type GeO_2 (r-GeO_2) is likely to satisfy these conditions because of its huge bandgap of 4.68 eV[1], bulk crystal growth by Czochralsk [2] and Flux[3], and predicted ambipolar dopability[4]. There are some reports of films grown on R-plane sapphire by MBE [5], on m-plane and c-plane by PLD[6,7]. However, synthesis of thick and smooth thin films is difficult, because of its high vapor pressure and close of synthesis energy levels of the rutile, amorphous and alpha quartz type, hence, making it very difficult to synthesize each phase completely separately.

Our group reported growth of r-GeO_2 thin films on rutile-type r-TiO_2 substrates with growth speed of more than 1μm/h by modified mist chemical vapor deposition (mist CVD) system [8]. Mist CVD is operated under atmosphere and required no vacuum system. However, detailed analysis of cross-sectional TEM observations at many points in the sample, poor-crystallized area was confirmed [9]. On the other hand, well crystallized region shows high-crystallinity with a thickness of 2 μm. At the present time, it is important to improve the uniformity of the GeO_2 thin film on hetero-epitaxial substrates for n-type or p-type conductivity control by doping.Furthermore, we suggested semiconductor alloy systems based on rutile-type GeO_2 for power device application [9]. The band gaps of the alloy can be tuned from 3.56 eV (SnO_2) to 8.75 eV (SiO_2). Experimentally, (Ge,Sn)O_2 alloy thin films were fabricated on TiO_2 (001) substrates with an entire range of Ge compositions. The bandgaps increase with increasing Ge composition in thin films. We believe that such basic research on GeO_2 is important for future power device applications.

This work was supported in part by Grants-in-Aid for Scientific Research (JSPS KAKENHI) Grant Number 21H01811 from MEXT, Japan.

References:

[1] M. Stapelbroek *et al.*, Solid State Commun. **25**, 959 (1978). [2] D. E. Swets, J. Cryst. Growth **8**, 311 (1971). [3] J. W. Goodrum, J. Cryst. Growth **7**, 254 (1970). [4] S. Chae *et al.*, Appl. Phys. Lett. **114**, 102104 (2019). [5] S. Chae *et al.*, Appl. Phys. Lett. **117**, 072105 (2020).
[6] G.Deng *et al.*, Appl. Phys. Lett. **119**, 182101 (2021) [7] G.Deng *et al.*, Materials Letters **326**, 132945 (2022).[8] H. Takane, *et al.*, Appl. Phys. Lett. **119**, 062104 (2021).[9] Errutum of Ref.[8]. [10]H. Takane, *et al.*, Phys. Rev. Mat. **6**, 084604 (2022).