SiC Lecture Series

8. SiC epitaxial growth technology

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SiC has many stable crystal polytypes. Therefore, to obtain an epitaxial growth layer that inherits a specific crystal polytype of the SiC substrate, it is necessary to impart the three-dimensional atomic arrangement information to the epitaxial growth layer, which requires some ingenuity. One method for achieving this is the epitaxial growth of SiC by chemical vapor deposition under appropriate growth conditions on a SiC substrate with a surface that has a small off-angle on a low-index plane. This method was discovered by Professor Emeritus Matsunami of Kyoto University and his colleagues, and it is named the Step-Controlled Epitaxy method.

Figure 1 shows a conceptual diagram of the epitaxial growth of SiC using the Step-Controlled Epitaxy method. By cleaning the surface of the SiC substrate with an off-angle, a structure of molecular layer-order steps and terraces is formed. When the source gas is supplied, the source species are delivered to this surface, where they move around on the terrace surface and are captured by the steps that appear here and there. The captured source species form crystals with an arrangement that matches the crystal polymorph of the underlying SiC substrate at those positions, resulting in the growth of the epitaxial layer.

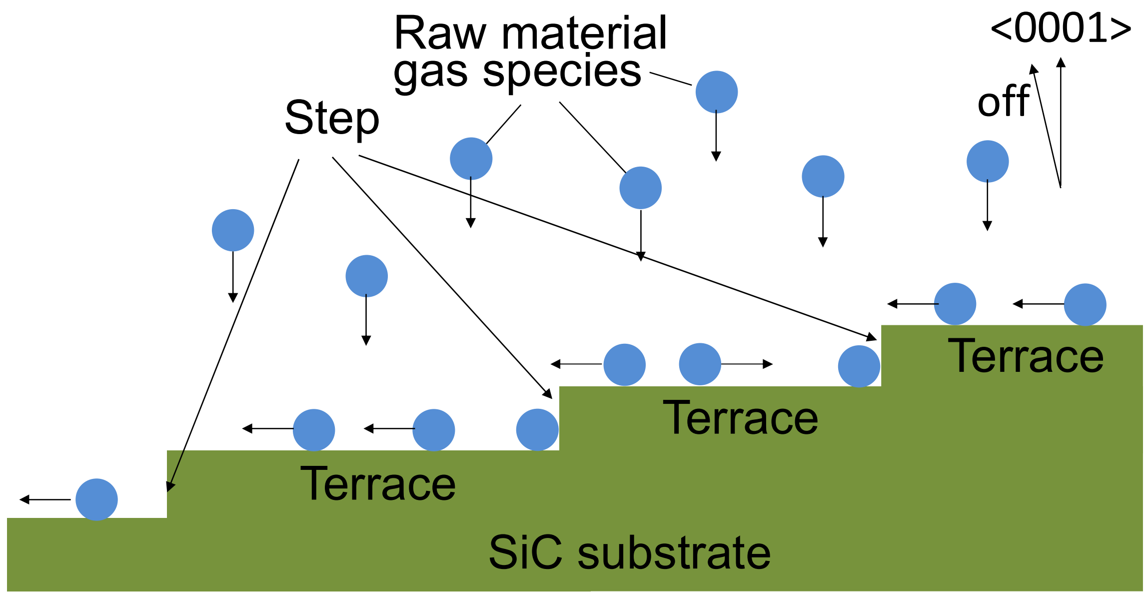

Figure 1 Conceptual diagram of SiC epitaxial growth on a (0001) substrate with an off-angle

In step-controlled epitaxy, if the source species nucleate and form crystals on the terrace surface rather than at the steps, the lack of vertical alignment information will result in the growth of crystals with different polytypes. Since the inclusion of different polytypes in the epitaxial layer constitutes a critical defect for devices, step-controlled epitaxy requires setting the off-angle to achieve an appropriate terrace width and optimizing conditions such as the concentrations of Si and C species in the source gas and the growth temperature to preferentially form crystals at the steps. Today, the surface of commercially available 4H-SiC substrates is set at a 4° off (0001) plane due to the dual requirements of step-controlled epitaxy and maximizing the number of wafers that can be obtained from a boule.

Epitaxial growth of SiC by chemical vapor deposition is typically carried out by supplying Si source materials such as SiH_4 and C source materials such as C_3H_8 to the surface of a SiC substrate maintained at a high temperature of 1500-1600°C, using high-purity hydrogen as the carrier gas. At such high temperatures, if the temperature of the surrounding areas, such as the inner walls of the apparatus, is low, the efficiency of supplying the source materials to the substrate surface is significantly reduced. Therefore, a hot-wall type reactor is used. Various types of SiC epitaxial growth apparatuses are employed, including vertical, horizontal, multi-wafer, and single-wafer systems. Figure 2 shows examples of gas flow and substrate arrangement in the reactor sections of various epitaxial growth apparatuses.

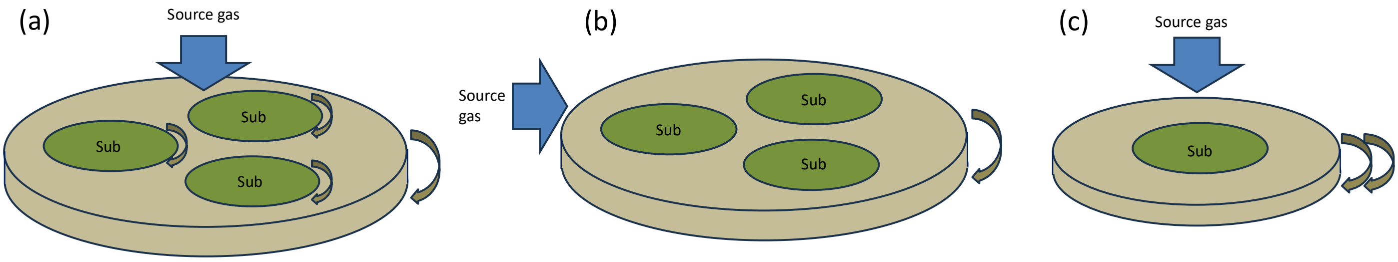

Figure 2 Gas flow and substrate arrangement
in the reactor section of SiC vapor phase growth apparatus
(a) Multi-wafer planetary type (from the top) (b) Multi-wafer planetary type (from the side)
(c) Single-wafer high-speed rotation type

When considering the mass production of SiC epitaxial substrates, factors such as the uniformity of the epitaxial layer thickness, the uniformity of doping concentration, particle generation, throughput, frequency of component replacement, and ease of maintenance need to be taken into account. The uniformity of the doping concentration is particularly important as it directly affects the breakdown voltage distribution of the device, requiring uniformity within the wafer surface, within the batch, and run to run. Currently, the development of SiC epitaxial growth equipment that supports 8-inch substrates is underway, and from the perspective of cost reduction, the realization of equipment more suitable for mass production is eagerly awaited. Additionally, since reaction products adhering to components inside the reactor and the exhaust system can become sources of particle generation, the development of gas etching methods that facilitate the removal of these products is also being pursued.

Epitaxial growth of SiC allows for the fabrication of power devices by the formation of high-purity SiC single crystal layers. In addition to this, epitaxial growth converts basal plane dislocations (BPDs) present in the substrate into threading edge dislocations (TEDs) at the substrate/drift layer interface (see Figure 3). As mentioned in Lecture 5, when a bipolar current flows, BPDs can expand as stacking faults, potentially causing degradation of device characteristics such as increased on-resistance. However, the converted TEDs do not affect the electrical characteristics of the device. Therefore, appropriate epitaxial growth can significantly reduce the origin of degradation due to bipolar conduction.

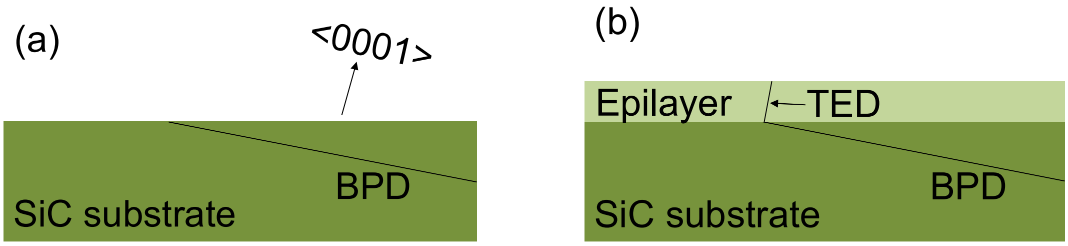

Figure 3 Cross-sectional schematic of BPDs and converted TEDs in SiC substrate and epitaxial layer (a) Before epitaxial growth (b) After epitaxial growth

In typical SiC epitaxial growth, a buffer layer is inserted between the drift layer and the substrate. The buffer layer is often heavily doped with n-type impurities, which promotes the recombination of minority carriers. The formation of the buffer layer also plays a role in the conversion of BPDs mentioned above and has a significant impact on cost, making it one of the important technologies in device fabrication.

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Power Device Works