Formation of non-vertical mesa structures on 4H-SiC RIE method using silicone-organic mask coating

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Abstract. The article discusses the possibility of using silicone lacquer as a masking coating when creating micro-dimensional mesa structures on the 4H-SiC surface using the reactive ion-plasma etching method. The etching process was carried out on a setup with an ICP plasma source. The experiments were performed with the aim of determining the dependence of the angle of inclination of the wall of the mesa structure on the parameters of the etching process. The etching results were recorded with a Helius nanolab instrument complex and a Quanta Inspec raster electron microscope.

1. Introduction
In recent time, avalanche photodiodes (APD) based on silicon carbide hexagonal polytype (4H or 6H) have rapidly developed. These devices can detect a super-weak signal. APD are very promising devices and have several advantages: small size, compatibility with standard CMOS technology, low supply voltage, lack of sensitivity to magnetic fields and low cost. The advantage of APD based on wide-gap silicon carbide material (SiC) is that they are able to detect ultraviolet (UV) radiation up to gamma radiation [1, 2].

One of the important conditions in creating APD process is to ensure stable operation under the application of high voltages. The main danger in application of high voltage is the breakdown of the structure, and in the case of APD, premature breakdown. Such a breakdown is most likely to occur at the periphery of the structure, where the surface and its quality play an important role. To ensure a fully volumetric breakdown, it is necessary to reduce the electric field strength at the boundary of the mesa structure.

There are several ways to increase breakdown voltage values, such as: field plates, guard rings, diffusion rings, and mesa structures with a tilt angle of more than 120° (chamfer-like structures) [3–4], etc. There are two types of chamfers – straight (positive) (figure 1, a) and reverse (negative) (figure 1, b).

Figure 1. Structures with p⁺-n transitions with straight (a) and reverse (b) chamfer.
The article is concerned with the formation of mesa structures on 4H-SiC with a large angle of inclination of the walls in fluorine, oxygen, and argon-containing plasma using KO-921 silicone lacquer as a masking coating.

2. Experimental

Prior to application of the silicon-organic lacquer KO-921, a complex liquid cleaning of the 4H-SiC surface was performed in a mixture of sulfuric acid (H₂SO₄) and hydrogen peroxide (H₂O₂) at a temperature of 60 ... 70 ºС. Next, the installation of the dosage “Averon” (figure 2) was applied with the drop method to the silicone lacquer KO-921 on the surface of 4H-SiC. The tilt angle of the silicone mask for different modes of application remained almost the same and was 115˚. The drop size can be controlled using nozzles with different geometrical dimensions (see table 1), as well as the selection of specified application parameters (“intensity” and “dosage”). There is a certain range of “dosage” and “intensity” values which provide the smallest size of the droplet diameter, with the metering nozzle selected, this range of values depends on the type of silicone lacquer. For lacquer KO-921 the values of "dosage" - 0.08 s and "intensity" - 0.7 s were selected experimentally, to achieve the minimum diameter of a drop on the 4H-SiC surface which was 1 mm.

![Figure 2. Technological installation "Averon" for the dosed supply of silicone-organic lacquer KO-921.](image)

| Dispenser-nozzle type | Diameter, mm | D, mm | L, mm | Minimal drop diameter, mm |
|-----------------------|--------------|-------|-------|--------------------------|
| BPN-30G-13            | 0.11         | 0.3   | 13    | 4                        |
| BPN-32G-13            | 0.11         | 0.23  | 13    | 2.5                      |
| BPN-34G-13            | 0.06         | 0.19  | 13    | 1.5                      |

According to the experiments, the etching rate of the KO-921 lacquer depends on the presence of oxygen (figure 3) in the plasma medium and the temperature in the reaction chamber.

Under selected technological parameters (magnetic coil current Iₖ = 1.2 A; gas flow rate: for argon F = 2.5 l/h, for oxygen F = 0.5 l/h, for sulfur hexafluoride F = 3.5 l/h; total pressure in the chamber P = 1.7 Pa). The etching rate of the KO-921 lacquer is 4 µm/min with power values applied to the ICP plasma source and the lower RF electrode of 350 W and 200 W, respectively, and the tilt angle of the resulting mesa structure is 168˚ while the depth is 2 µm (figure 4).

It has been found experimentally that the etching rate of a KO-921 siliconeorganic lacquer is affected by the presence of oxygen in the plasma medium, as shown in figure 3, and with an increase in the O₂ percentage, the etching rate of the KO-921 lacquer increases. In the absence of oxygen, the etching rate of silicon carbide decreases by several times, since the presence of oxygen in the plasma promotes the formation of volatile compounds (CO, CO₂, etc.) during the etching process, while the
etching rate of the silicon-organic lacquer does not slow down much (~ 2.5 µm / min). At 10% oxygen content in plasma, selectivity with respect to 4H-SiC is 8. Therefore, silicone-organic lacquer KO-921, as a masking coating, can only be used when creating shallow mesa structures (up to 3 µm).

![Graph showing etching rate vs. oxygen content](image)

**Figure 3.** Dependence of the etching rate (µm/min) of lacquer KO-921 on the concentration of oxygen (%) in etching gas mixture.

![SEM image of non-vertical mesa structure](image)

**Figure 4.** SEM image of the non-vertical mesa structure on 4H-SiC formed by the RTDT method using KO-921 silicone-organic lacquer mask coating.

### 3. Conclusion

The possibility of the formation of non-vertical mesa structures on 4H-SiC by the RIE method in fluorine, oxygen and argon-containing plasma at a technological installation with an ICP plasma source "Caroline PE 15" using KO-921 silicone-organic lacquer as a masking coating has been investigated. Using this masking coating it is possible to form micro-dimensional non-vertical mesas over 160 °. During the technological preparation of lacquer KO-921 (“Dose” - 0.08 s, “Intensity” - 0.7 s, Dispenser BPN-34G-13) the angle of the mask is 115° and the diameter is 1 mm. It has been shown experimentally that during RIE 4H-SiC process in an oxygen-containing plasma, the silicone-organic varnish, as a masking coating, demonstrates a low selectivity.

The masking coating on the basis of silicon-organic lacquer KO-921 proved promising for using in the field of creating a shallow (up to 3 µm) mesa structures on 4H-SiC (the technology is relevant for creating avalanche photodiodes and power electronics devices). In the future, work is underway to increase the selectivity of 4H-SiC and to increase durability during etching of KO-921 silicone-organic lacquer in oxygen-containing plasma.
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