Photoelectrical characteristics of Ga$_2$O$_3$-GaAs structures

V.V. Vishnikina, V. M. Kalygina, Yu. S. Petrova, I. A. Prudaev
National Research Tomsk State University, 36 Lenin Prospekt, Tomsk, Russia
E-mail: vishnikina.vera@rambler.ru

Abstract. The influence of thermal annealing and exposure in oxygen plasma on photoelectrical characteristics of Ga$_2$O$_3$-GaAs structures in visible and UV-region is investigated. Thermal annealing enhances the transparency of Ga$_2$O$_3$ films in visible range and leads to the appearance of photocurrent in Ga$_2$O$_3$-GaAs-structures. Ga$_2$O$_3$ films absorb UV-radiation beginning with 240 nm and lower.

1. Introduction
Thin Ga$_2$O$_3$ films have a wide variety of applications including the fabrication of gas sensors, solar-blind photodetectors, phosphors and other devices. Also such films are applied as transparent conductive electrodes and antireflection coatings. It is known that films’ properties are determined by conditions of obtaining and processing. So the purpose of this work is investigation of how high-temperature annealing and treatment in oxygen plasma influence on photoelectrical characteristics of MOS-structures. Ga$_2$O$_3$ can be found in five different phases which differ from each other by crystalline structure. β-phase is the most interesting. It is the most chemically and thermally stable crystalline modification. It is known from literature that Ga$_2$O$_3$ films are transparent enough to visible light. And such films can be used as transparent conductive electrodes in optoelectronic devices. It is interesting to investigate how high-temperature annealing and O$_2$ exposure influence on photoelectric phenomena in such structures.

2. Experiment details
All samples were fabricated on GaAs epitaxial layers (N$_d$ = 8.9·10$^{15}$ cm$^{-3}$) grown on n-type GaAs substrates (n$_0$ ≈ 10$^{18}$ cm$^{-3}$). In the first stage standard chemical purification is conducted. Ga$_2$O$_3$ films were grown by photoelectrochemical oxidation method (or anodic oxidation). It is the most sparing method for obtaining thin films. As the result oxide of gallium and oxide of arsenic are formed. In order to remove an easily volatile oxide of arsenic the annealing in atmosphere of hydrogen is conducted (300 °C, 10 min). In order to obtain β-phase the annealing in argon at 900 °C (30 min) is carried out. After that the samples were exposed to the oxygen plasma (20, 30, 50 min, 90 °C). The phase composition of our films was determined by X-ray diffraction analysis (XRD). The surface morphology was investigated by an atomic force microscope (AFM).

3. Results and discussion
It is important to notice that as-grown films were amorphous. According to the results of XRD (Figure 1) it can be assumed that introduction of oxide atoms in Ga$_2$O$_3$ lattice leads to the formation of β-phase crystallites with different crystallographic orientation [1, 2].
Figure 1. Spectra of X-ray diffraction: \( a \) – treatment in \( \text{H}_2 \) and 20' in \( \text{O}_2 \); \( b \) – treatment in \( \text{O}_2 \) 20', annealing in \( \text{Ar} \) (900 °C, 30'); \( c \) – treatment in \( \text{O}_2 \) 50', annealing in \( \text{Ar} \) (900 °C, 30'); \( d \) – treatment in \( \text{O}_2 \) 20' after annealing in \( \text{Ar} \) (900 °C, 30')

From the AFM-analysis it is evident that annealing led to a change in the microstructure from an amorphous to a polycrystalline phase (Figure 2-4).

The reduction of charge carriers concentration takes place in GaAs after the growth of \( \text{Ga}_2\text{O}_3 \) film. Such effect depends on the duration of \( \text{O}_2 \) exposure (Figure 5).

Figure 5. The concentration of charge carriers in \( n \)-GaAs after high temperature annealing at different duration of \( \text{O}_2 \) exposure
Figure 2. Two-dimensional image (a) and three-dimensional image (b) of Ga$_2$O$_3$ film surface (without treatment in oxygen plasma and annealing in Ar).

Figure 3. AFM picture of Ga$_2$O$_3$ surface after annealing (900 °C), without treatment in oxygen plasma - two-dimensional (a) and three-dimensional (b).

Figure 4. AFM picture of Ga$_2$O$_3$ surface after annealing (900 °C), treatment in O$_2$ before annealing (50 min.) – two-dimensional (a) and three-dimensional (b).
Photoresponse is observed for samples after only high-temperature annealing. Photocurrent is explained by the generation of charge carriers in the space charge region of the semiconductor. After 20 minutes of O₂ exposure we obtain the most transparent films for visible light (Figure 6).

![Figure 6](image1.png)

**Figure 6.** Reverse dark and light current-voltage curves for samples after thermal annealing and O₂ exposure

![Figure 7](image2.png)

**Figure 7.** The spectral dependence of the sensitivity of Ga₂O₃-GaAs structures according to the duration of O₂ exposure

Similar with the visible range the influence of UV-radiation on structures without high-temperature annealing isn’t observed. Maximum sensitivity is observed for samples after annealing at 900 °C which were exposed to the oxygen plasma during 20 minutes. In our experiment sensitivity increases from 240 nm to 200 nm – in this region of wavelength gallium oxide films are not transparent and absorb the radiation (Figure 7).

4. Conclusion

The connection between the duration of oxygen plasma treatment and the emergence of β-phase crystallites with different crystallographic orientation is established. It is shown that after high-temperature annealing the films become transparent in visible range and photocurrent is explained by the generation of charge carriers in the space charge region of the semiconductor. Ga₂O₃ films absorb UV-radiation from 240 nm.

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References

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