Low Temperature Oxidation of GaAs by UV Stimulated Plasma Anodizing

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Abstract. In this paper we offer low temperature technology receiving GaAs oxide. For this purpose, we use plasma anodizing with ultraviolet irradiation. Formation native oxide of GaAs is a problem and solving this problem is a scientific challenge. This paper provides the information about the kinetic of growing GaAs oxide, measurement of C-V characteristic, analysis of XPS spectra and Auger Spectroscopy, the distribution profiles of oxygen, Gallium and Arsenide in the total oxide, surface roughness and state density dependence on the anodizing current.

1. Introduction

Formation of oxide films in the world happens in high temperatures (11 000°C). At this temperature take place diffusion of unwanted impurities, increasing porosity, becoming worst adhesion to the substrate and etc. All of this influences badly on the parameters of nano-scale devices. In the current researches it is actual to increase the switching speed of integral circuits. For this purpose, the GaAs is a perfect material, which has good electrical and physical properties. Such as high electron mobility and their saturation high speed. But the silicon technology is not useful for GaAs based integral circuits technology, because temperatures higher than 5000°C take place destroying of GaAs structure. In this paper we offer low temperature (300-4000°C) technology receiving GaAs oxide. For this purpose, we use plasma anodizing [1] with ultraviolet irradiation. It is well known that achieve native oxide of GaAs is a problem [2]. Solving this problem is a low temperature technology. The scientific essence of the plasma anodizing is as following: in the general case plasma anodizing is performed under positive voltage applied to the material to be oxidized, which leads to oxidize samples with negatively charged oxygen ions extracted from the plasma. In this process, oxidation current contains many electrons, compared to negatively charged oxygen ions and therefore the process efficiency becomes low [3]. For this reason and for increasing process efficiency in the process of anodizing simultaneously is switched on UV irradiation. UV irradiation acts as a stimulation of plasma anodizing process. Irradiation by UV spectra creates in the oxide-semiconductor interface small energetic levels and small positive charge. Beside of this effect, the oxide layer thickness is more uniform.

We have studied electrical, optical and structural properties of GaAs oxide. Electrical properties were characterized by Capacitance-Voltage measurement, structural properties - Auger and XPS spectroscopy.


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2. Experiment

In the experiment, we used (100), 10 Ω·cm, 2 inch, p-type GaAs wafers. It was placed in plasma anodizing vacuum chamber (Figure 1) for anodization. After receiving high vacuum (10-6 torr) by diffusion pump, the sample was heated to 3500C and in the chamber were entered Ar and O2 gases with ratio 2:8 respectively by needle valves. At a set pressure 10-2 torr was applied voltage 300-400 V between anode and cathode and plasma current were 0.8÷1A.

During GaAs oxidation resistivity is increased and anodizing current must be dropped, therefore we had increased the voltage step by step so, that hold the anodizing current constant and process curies at a constant current.

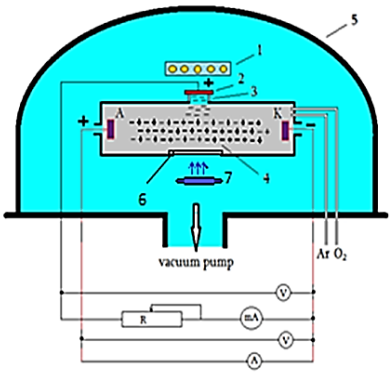

Figure 1. Plasma anodizing system with electrical circuit; 1) substrate; 2) isolators; 3) local plasma area; 4) vacuum chamber; 5) UV bulb; 6) Quarts plate;

3. Stimulated Plasma Anodizing

The scientific essence of the plasma anodizing is as following: in the general case plasma anodizing is performed under positive voltage applied to the material to be oxidized, which leads to oxidase of the samples with negatively charged oxygen ions extracted from the plasma. In this process, oxidation current contains many electrons, compared to negatively charged oxygen ions and therefore the process efficiency becomes low. If the process curries without UV irradiation the process speed is very low and growth thicknesses are about several atomic layers. For this reason and for increasing process efficiency in the process of anodizing simultaneously, the UV radiation is switched on. At this time, speed of anodizing process increases. In the process of anodizing in the surface of GaAs happens intensively absorption of UV quants and as a result causes bond breaking between GaAs and oxygen. Released oxygen moves freely by applied positive potential on the substrate and advancing from the surface to its depths. At the same time, more oxygen ions from the plasma to the surface come, which can't form a bond with GaAs due to UV radiation and continues migration as well as to the depth of the metal. In this time the process efficiency and oxidation speed increases significantly.

After entering a certain depth, oxygen ions movement slows down, because UV irradiation does not influence in the depth caused by UV quantum energy absorption and oxidation process speed reduces. Despite of process speed reduction, by this method can be accepted up to 50 nm oxide layers and most importantly in the short time. Moreover, substrate is placed at a distance upstream from plasma region so that the main plasma is relaxed in the vicinity of the substrate (Figure 2), in order that the oxidation is more chemical in nature. It seems that plasma anodizing process is a combination of stimulated, anodizing and remote plasma enhanced oxidation processes.

Stimulated plasma anodizing develops owing to a reduction in the activation energy for oxidation of the material [4]. In general, this reduction is caused by the formation of new intermediate complexes (Ga-O, As-O complexes in the case under consideration), which changes the shape and lowers the height of the potential barrier (Figure 3). As a result, the reaction can proceed via a new channel that involves a barrier with a lower height.

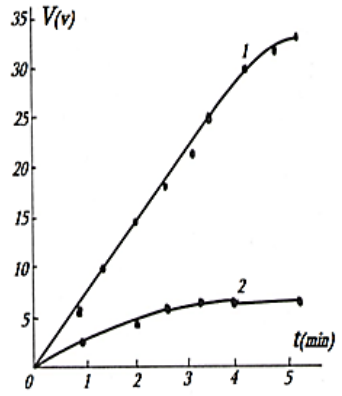

Figure 2. Kinetic of growing GaAs oxide

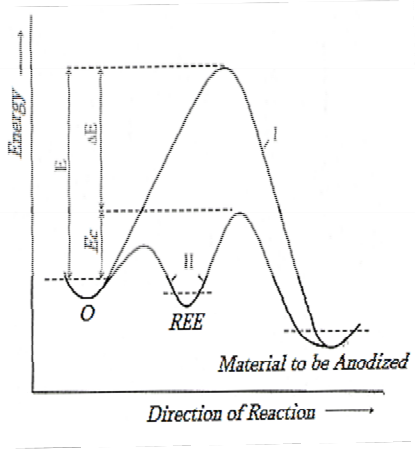

Figure 3. Potential barrier of oxygen atoms in the anodization process with catalyst (II) and without catalyst (I)

4. Results and discussion

Figure 4 shows the $_xGa_2O_{3+y}As_2O_3$ native oxide and GaAs surface profile. Calculated thickness is 491 Å and roughness is 11 Å and 15 Å respectively.

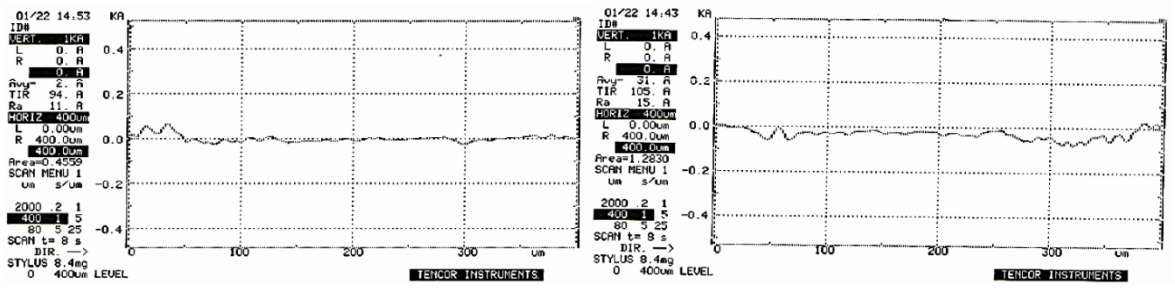

Figure 4. Profilometer data: a) $xGa_2O_3+yAs_2O_3$, b) GaAs

Figure 5 shows Distribution profile (Auger-spectroscopy) of elements (1-O; 2-Ga; 3-As) of plasma anodizing GaAs.

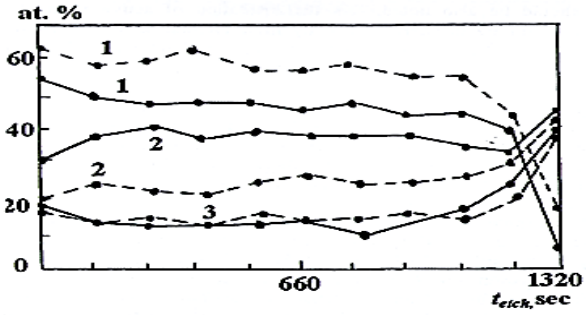

Figure 5. Distribution profile (Auger-spectroscopy) of elements (1-O; 2-Ga; 3-As) of plasma anodizing GaAs (---- without stimulation process; — with UV stimulation)

In the case of stimulation process plasma anodizing of GaAs, oxygen distribution profile drops. It is because free oxygen ions, which were in the interspace area, make bonding with Ga atoms and decreases oxygen composition in the total oxide. Respectively, in the same process Ga oxide contribution in the native oxide increases, which is clearly showed from distribution profile. For As oxide, it is non-stabile

oxide and stimulated or without stimulation processes doesn't change As composition in the total oxide [5].

Fig.6 shows C-V normal characteristics of GaAs oxide: 1) without stimulation process; 2) with UV stimulation. In both cases oxide charge is positive and charge is less in the case stimulation than without stimulation process.

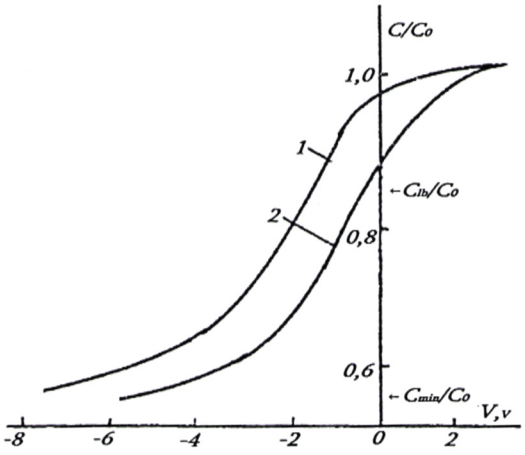

Figure 6. C-V characteristics

The parallel parts of the curve show, that state density in the interface dielectric-semiconductor is equal in the stimulated and without stimulation processes.

Fig 7. shows XPS spectra for $A_{s2}O_3$ (a) çð $G_{a2}O_3$(b) for GaAs substrate. The Fig.7 spectra indicates that in the native oxide of GaAs the spectra of Ga and As is swift to a GaAs spectra,which proofs existing both components – oxides of Ga and As.

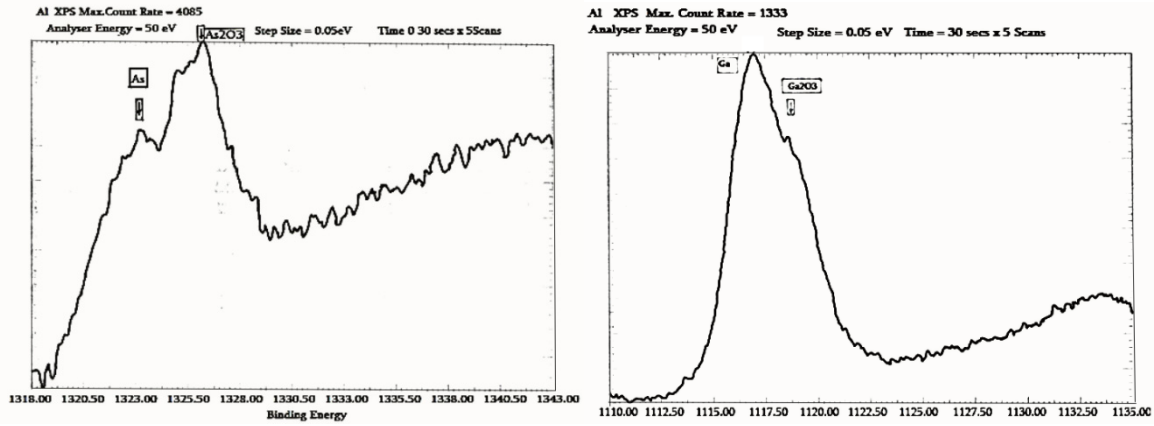

Figure 7. XPS spectra

Figure 8 shows dependence of surface state density (1) and charge on the anodization current density. From the figure 8 seems, that minimal surface states and charge in the oxide can be reached for the anodizing current 1.9 mA/cm^2, which is optimal parameter in the process plasma anodizing.

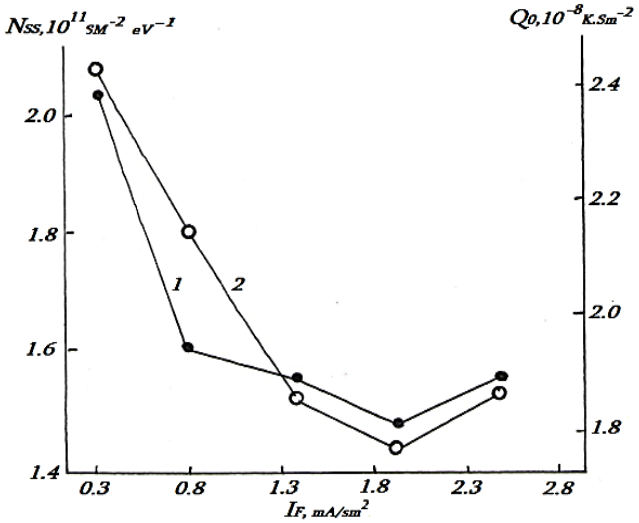

Figure 8. Dependence of surface state density (1) and charge on the anodization current density

5. Conclusion

In the present work, GaAs oxide properties were studied. It was clearly showed by kinetic of growing GaAs oxide, that UV stimulated process is high speed oxidation process comparing to with process without stimulation. By C-V characterization was showed that in the oxide layer is a positive charge. XPS spectroscopy showed existence of GaO and AsO in the separate phase. By profilometer was calculated thickness and roughness of the GaAs oxide. From the dependence of surface state density and charge on the anodization current density was calculated the optimal parameter of anodizing current which is 1.9 mA/cm^2.

Acknowledgment

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