Gallium Oxide Based Memory Switching Device

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Abstract

In recent decades, semiconductors with a large band gap (SiC, GaN, AlN, ZnO) have gained great interest and wide application in technology and everyday life. For many decades, devices based on silicon (Si) dominated the field of electronic devices. Substantial progress was achieved with the commercialization of the transistor in the 1980s, the creation of the bipolar junction transistor (IGBT) in the 1990s, and the production of the p-n junction transistor in the 2000s. Every significant improvement in devices based on silicon as the base semiconductor material has been due to the clever formation of the p-n junction. However, since 2010, devices based on other systems have entered the market, and the focus has shifted from p-n junction engineering to materials engineering. In contrast to the wide bandgap materials listed above, the ultra-wide bandgap (4.7–4.9 eV) semiconductor gallium oxide (Ga_2O_3) is the only material that can be grown from the liquid phase and is therefore a potentially low-cost material. It forms five crystalline polymorphs. The β phase is the only stable polymorph above 1800°C and 1atm pressure. The use of melt-based growth techniques provides significant manufacturing advantages, cost, and scalability compared to vapor-deposition processes used for other wide bandgap semiconductors such as SiC, GaN, and AlN. This paper discusses the production of gallium oxide (Ga_2O_3) by reactive magnetron sputtering technology and its use in a memory device - memristor, as an active layer. Various technological conditions are selected to obtain the best physical, electrical, structural and optical parameters of gallium oxide. Volt-Faradic, Volt-Siemens, Volt-Amperic, X-ray diffraction, optic transmission spectra and Kelvin methods of measurement are used. The ratio of low resistance and high resistance is shown, calculated from the volt-amperic characteristic of the memristor.

Keywords: *Semiconductor, band gap, technology, oxide, memristor*

1. Introduction

At the present stage, the creation of high-quality information and communication systems requires the improvement of the quality and use of appropriate semiconductor materials. Recently, the energetically wide-bandgap promising semiconductor material gallium oxide (Ga_2O_3) has attracted much attention from researchers in both fundamental and applied fields [1-4]. It is of particular interest to use it for the creation of high-temperature, fast-acting and high-frequency (HEMT) transistors, memory elements and other micro- and nanodevices that consume little energy. Therefore, it is interesting to use gallium oxide in memory device - memristor [5,6]. Memristore based on gallium oxide active layer will be faster, save more information and consume less energy [7-8]. The establishment of a new material in technology requires the selection and development of the technology for obtaining this material, its optimization, study electro-physical, optical, mechanical and other parameters of the resulting material.

2. Experimental

The reactive magnetron sputtering method was used to obtain nanoscale gallium oxide films. In a magnetron system target material is bombarded with introduced gases (0+, Ar+). atoms of the sputtered material are reacted chemically with oxygen atoms and as a result Ga_2O_3 is deposited on the substrate placed on the top of the magnetron. This technological process is low-temperature ($T \leq 700^0C$), ensuring process repeatability and precise control of gas partial pressures in vacuum.

As substrates, were used n-type 2-inch silicon (Si) wafers with the 4.5 ohm.cm resistivity and surface orientation (100) and 2-inch sapphire (Al_2O_3) wafers with the surface orientation (0002). Before the deposition of gallium oxide, the surfaces of the wafers were chemically cleaned in a standard manner.

It was experimentally established that Ga_2O_3 and Al are etched in the same solution and that for photolithographic processes on the oxide, tungsten (W) must be deposited under Al, which will protect the oxide from chemical attack. Therefore, after Ga_2O_3 layer, a thin (~150Å) layer of tungsten (W) was deposited on the sample, also by the magnetron sputtering method.

Gallium oxides were obtained in the pressures range $(2.7 \div 3.2) \cdot 10^{-2}$ Pa, sputtering current 150mA, voltage U=270V, and coating temperature T=350°C. The O_2/Ar ratio was measured with a mass spectrometer (RGA 200) and varied in different intervals, which are given in Table 1.

Tab. 1. Technological parameters of magnetron sputtering

Oxide	P_{O2} (%)	P_{Ar}(%)	Time, (min)	Thickness, (nm)
Ga_2O_3	50	40	60	72
Ga_2O_3	60	30	60	67.5
Ga_2O_3	40	50	60	122
Ga_2O_3	30	60	60	180
Ga_2O_3	20	70	60	200
Ga_2O_3	70	20	60	81
Ga_2O_3	100	0	60	67.5

3. Results and Discussion

The metal-oxide-semiconductor structures (Fig. 1) were studied using Volt-Faradic (C-V) methods at different partial pressures of oxygen and argon (Fig. 2). From Fig. 2 can be seen that the 7th curve is better in terms of the density of charge in the oxide and the oxide-semiconductor trapping levels at the interface, i.e. when oxygen is 100%.

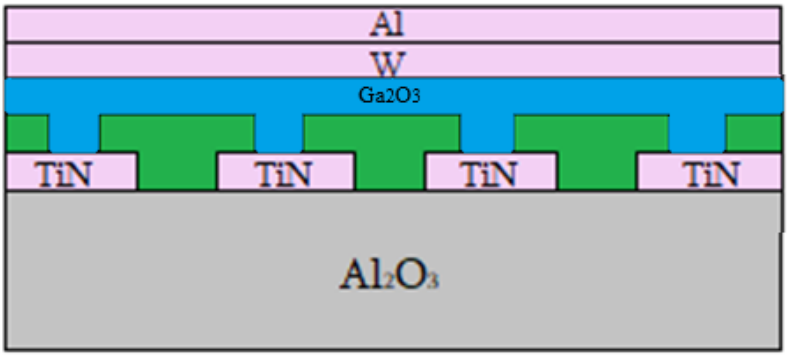

Fig. 1. MOS-Memristore structure.

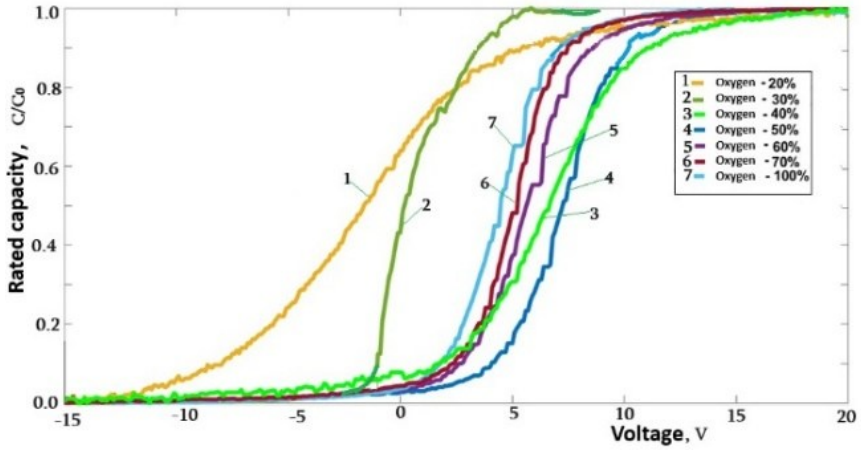

Fig. 2. Volt-Faradic MOS structures

The X-ray structural analysis of the obtained oxides was carried out by the X-ray diffraction (XRD) method. The study was carried out on a DRON-4-07 type device. Three slits of the same size were used to obtain a parallel beam of X-rays – 0.1 θ. The operating mode was: accelerator voltage 21 kV; current 10 mA; recording speed 2°/min; threshold intensity 1000 imp/s. Fig. 3 and Fig. 4 show X-ray diffraction curves of Ga_2O_3 grown on silicon and sapphire substrates, respectively. It can be seen from Figure 3, that the peak corresponding to Ga_2O_3 is located between the diffraction angles of $58.5^0 \div 64^0$. It is amorphous. At other diffraction angles, diffraction lines are not observed, which indicates its X-ray amorphous nature. To study optical properties of the Ga_2O_3 obtained by magnetron sputtering, we studied its transmission spectra in a wide optical range λ = 190-1100 nm (Fig. 5), when substrate was sapphire substrate.

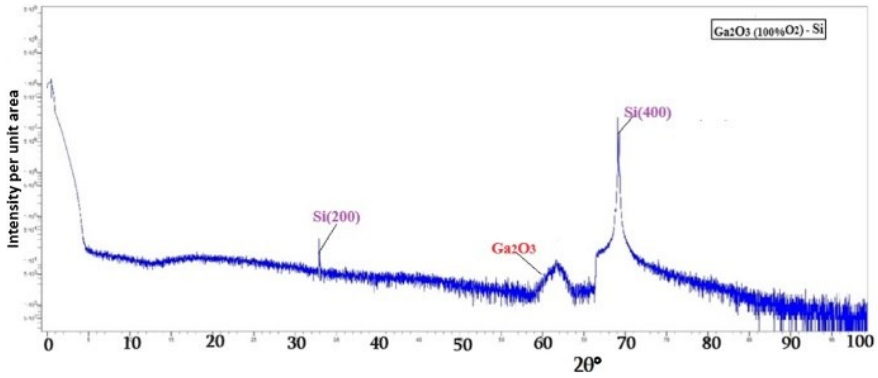

Fig. 3. XRD pattern of Ga_2O_3 deposited on silicon substrate.

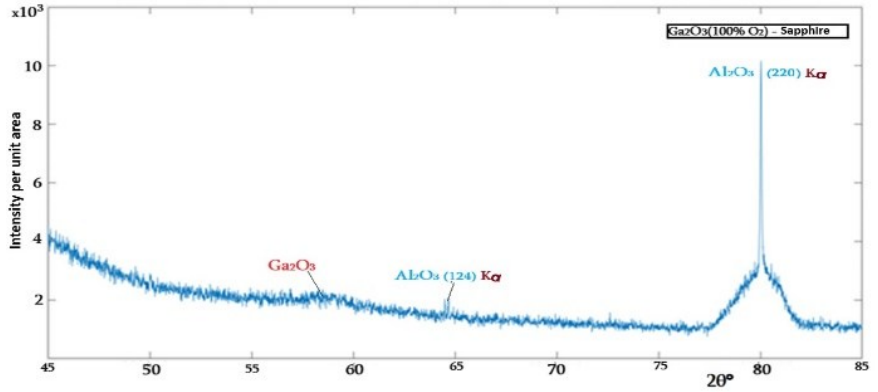

Fig. 4. XRD pattern of Ga_2O_3 deposited on sapphire substrate.

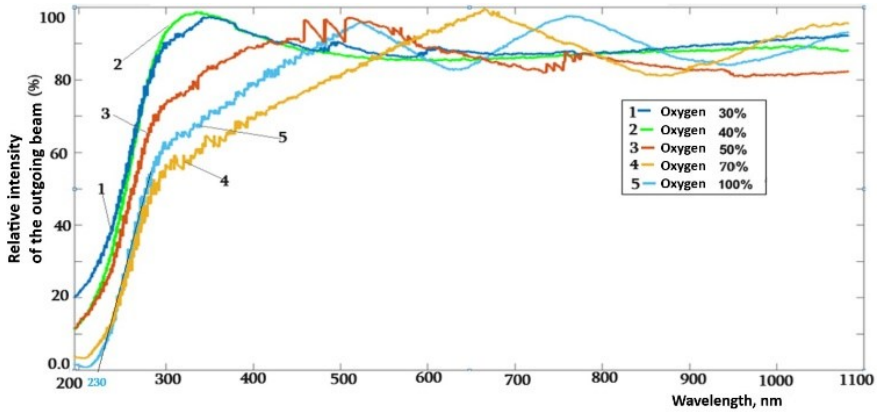

Fig. 5. Transmission spectra of Ga_2O_3 obtained at different O_2/Ar ratios

As can be seen from Fig. 5, in terms of the transmission spectrum, the best is the 5th graph, i.e. when pure oxygen (100%) was used to obtain gallium oxide. From this, the width of the forbidden band of gallium oxide was determined to be 4.45 eV. The work function of gallium oxide was measured using an original device built on the basis of the Kelvin method. It is based on recording the change in the induced charge generated by the vibration of a metal needle relative to the material of the measuring film. The experiment showed that the work function of gallium oxide is 5.39 eV. I-V characterization (Fig. 6) showed hysteresis behaviour in the applied voltage range -1.4÷1.4 V. From the I-V curve was calculated R_{off}/R_{on} ratio, which equals 130.

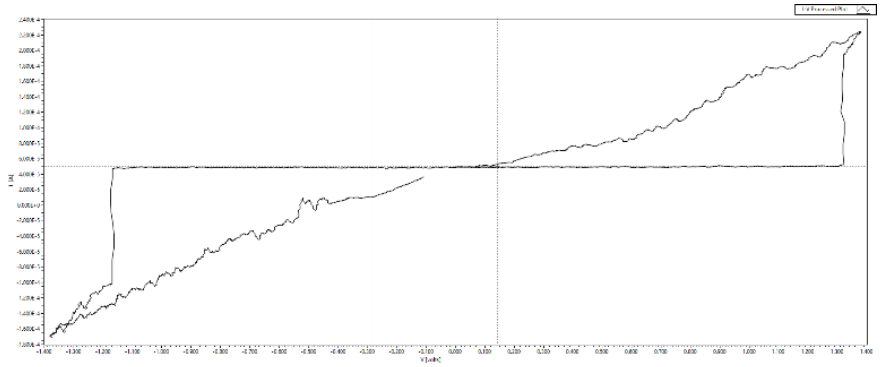

Fig. 6. I-V characterization of the memristore.

4. Conclusions

We have studied the reactive magnetron sputtering technic for receiving gallium oxide and embedded this material memristore as an active layer. Research outcomes show that Ga_2O_3 band gap is around 4.45 eV calculated from the transmission spectra. Work function, which was measured by Kelvin probe technic revealed uniformity of the surface and calculated value of work function was 5.39 eV. I-V characterization of the memristore showed hysteresis and calculated R_{off}/R_{on} equals to 130. As a result, from this research we can assume that magnetron sputtering technology is suitable for growing wide band gap materials, following using them in the electronic, opto-electronic and memristive nano-devices.

Acknowledgments

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