acta phys. slov. 35 (1985), No. 2

ANODIC OXIDATION OF GaAs IN THE OXYGEN PLASMA OF THE HF DISCHARGE[1]

E. PINČÍK[2], I. THURZO[2], J. BARTOŠ[2], J. DILINGER[3], P. KÚTIK[3], Bratislava

The paper presented is concerned with the constant voltage mode of the plasma anodic oxidation process at two substrate temperatures. Some electrical properties of GaAs MOS structures such as resistivity, breakdown field strength, relative permittivity have been evaluated. We show GaAs MOS C–V curves and the U-shaped continuous spectrum of states at the interface. The possibility of utilizing these structures for producing of GaAs IGFET's is discussed.

АНОДНОЕ ОКИСЛЕНИЕ GaAs В КИСЛОРОДНОЙ ПЛАЗМЕ ВЫСОКОЧАСТОТНОГО РАЗРЯДА

В данной работе рассматриваются вопросы процессов плазменного анодного окисления в режиме постоянного напряжения при двух температурах субстрата. Вычислены некоторые электрические свойства МОП-структур на основе GaAs, такие как удельное сопротивление, пробивная напряженность электрического поля и относительная диэлектрическая проницаемость. Построены C–V кривые МОП-структур на основе GaAs и U-образный непрерывный спектр состояний на границе раздела. Проводится также анализ возможностей использования этих структур для производства IGFET-транзисторов на основе GaAs.

I. INTRODUCTION

The formation of insulating films on the surface of GaAs substrates is important for the production of semiconductor devices, e.g. GaAs IGFET's and GaAs MESFET's and also for surface passivation. Various papers have been published dealing with the technology of these structures. Thus, e.g. the Sugano group has

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[1] Contribution presented at the 5th Symposium on Elementary Processes and Chemical Reactions in Low Temperature Plasma. ŠTIAVNICKÉ BANE, May 21—25, 1984.

[2] Institute of Physics, EPRC Slov. Acad. Sci., Dúbravská cesta, 842 28 BRATISLAVA, Czechoslovakia.

[3] Dept. of Physics, Fac. of Engineering Slov. Techn. Univ., Gottwaldovo nám. 17, 811 06 BRATISLAVA, Czechoslovakia.

studied plasma anodic oxidation using oxygen plasma at different parameters such as pressure, chip temperature, anodization voltage, position of the substrate with regard to the centre of the discharge [1].

The above have been applied in a constant current mode at a current density 53 Am^{-2}. One of the conclusions has been the fact that only the low temperature anodic oxidation is suitable for forming good insulator films on GaAs. The arsenic evaporates from the substrate more intensively above 300 °C and the stoichiometry of the surface oxide layer breaks.

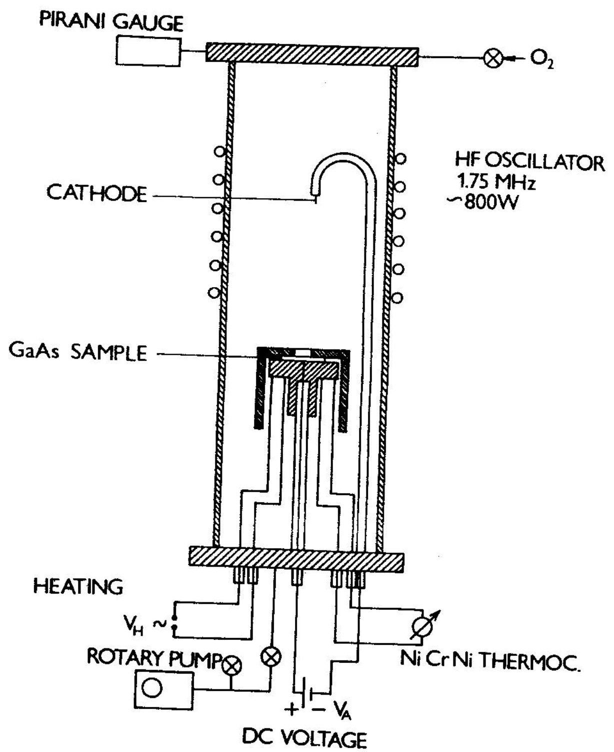

Fig. 1. The scheme of the anodization apparatus.

II. METHOD AND SET-UP FOR ANODIC OXIDATION

Wafers of an n-type bulk GaAs with carrier concentration of $(1-4.5)\times 10^{24}\ m^{-3}$ and surface orientation of (100) were used in the present experiments. These data are provided by the manufacturer. The scheme of the anodic apparatus is illustrated in Fig. 1. A quartz pipe, the diameter of which is 70 mm and the length 750 mm, is used. Oxygen was supplied through a needle valve from the upper circular flange. The whole system was evacuated to the pressure of 1—3 Pa and then filled with oxygen to the pressure of 25 Pa. The pressure was measured with a Pirani gauge calibrated on oxygen. The oxygen plasma was generated by a high frequency 1.75 MHz field applied through a 6 turns coil surrounding the pipe. The HF input power was about 800 W. The gallium arsenide substrate was always mounted outside the region of the inductive coil on a support heated with kanthal wire. The substrate was positively biased at 60 V with respect to the plasma by an electrode in contact with the back side of the substrate. The voltage was kept constant during the whole oxidation process. Leakage paths were eliminated so that practically all the dc current could flow through the gallium arsenide substrate. The Pt cathode electrode was located in the centre of the plasma.

III. RESULTS AND DISCUSSION

III.1. Oxidation process

When the dc current is supplied by a dc constant-voltage source through a 40 Ω resistor, the growth of the oxide film is comparatively fast at the initial stage. The anodization process was investigated at a constant voltage mode with 60 V and two temperatures of the substrate: between 110 °C and 120 °C, resp. between 270 °C and 290 °C. The distance between the gallium arsenide anode and the Pt cathode was 65 mm. The oxide thickness was measured by the ellipsometric method with a sodium-vapour lamp as the light source.

Fig. 2 shows the oxide thickness as a function of the oxidation time for the pressure 25 Pa in the system. The initial growth rate was about 0.46 nms^{-1} at a higher and 0.38 nms^{-1} at a lower temperature, respectively. The difference in the growth rates is not as marked as expected, e.g. for a glow discharge oxidation process [2].

About 80 samples were prepared. They had a good reproducibility of the oxide thickness growth in dependence on the oxidation time.

The real value of the oxygen partial pressure is questionable, since the system is evacuated by a rotary pump. The analysis of the residual gases was not made.

The refractive index of the oxide was found to be approximately 1.9.

III.2. C-V characteristics

The electrical properties of the oxide and the interface between the oxide and GaAs substrate were determined from the capacitance-voltage measurements on the MOS diodes. These measurements were made by the apparatus which is illustrated schematically in Fig. 3.

The flat-band voltage of these structures is 5—10 V at room temperature. The donor concentration $N_d = (9 \times 10^{23} - 3 \times 10^{24})\ m^{-3}$ has been determined from the dependence C^{-2} on the bias voltage U_g. The resistivity and breakdown field strength of most oxides are $10^{16} - 10^{17}\ \Omega m$ and about $10^8\ Vm^{-1}$ respectively, by our measurements. Curves in Fig. 4 show typical dependences of the capacitance on the bias voltage U_g of the MOS structures for an oxide thickness of 65 nm.

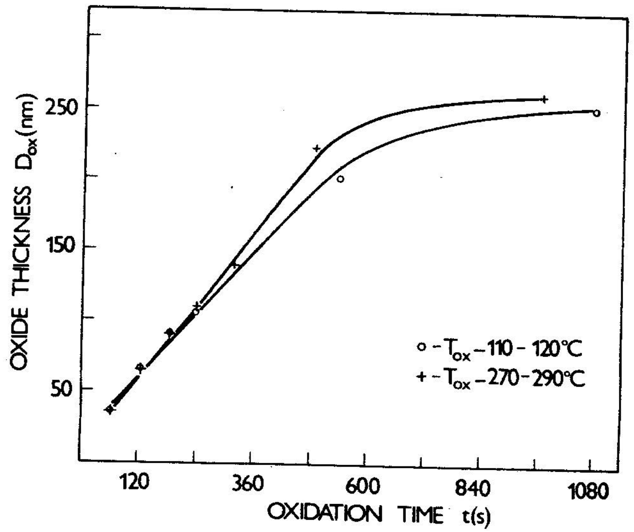

Fig. 2. Dependence of the oxide thickness on the oxidation time at two temperatures of the GaAs sample.

The measurements of C-V characteristics were made at a frequency of 1 kHz. They are similar for thicker oxides but the hysteresis and the dynamics become smaller. The dynamics is the relative difference between the capacitance in accumulation and the depletion modes. This is caused by the fact that the thinner the oxide is the larger is the part of the bias voltage U_g which exhibits the voltage-dependent capacitance.

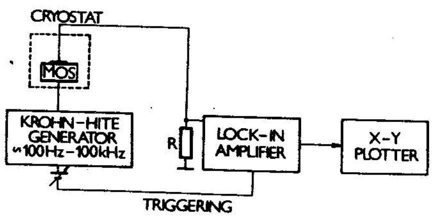

Fig. 3. The scheme of the apparatus for measurements of GaAs MOS C-V curves.

Table 1

D_{ox} [nm]	67	90	140	213	263
ε_{ox}	9.7	8.7	10.1	10.5	8.3

The permittivity of the oxide was evaluated from the measured capacitance of the MOS diodes in accumulation. The results are shown in Table 1.

The values of the relative permittivity range from 8 to 11 are in agreement with published results in [2], [3] and [4]. There is an interesting course of the capacitance at low temperature, the hysteresis of the C-V curve becoming larger and the overall capacitance smaller. The change of the capacitance in dependence on temperature is the clearest for the thin oxide. The relative change of the capacitance between — 180 °C and 20 °C versus oxide thickness D_{ox} is illustrated in Fig. 5.

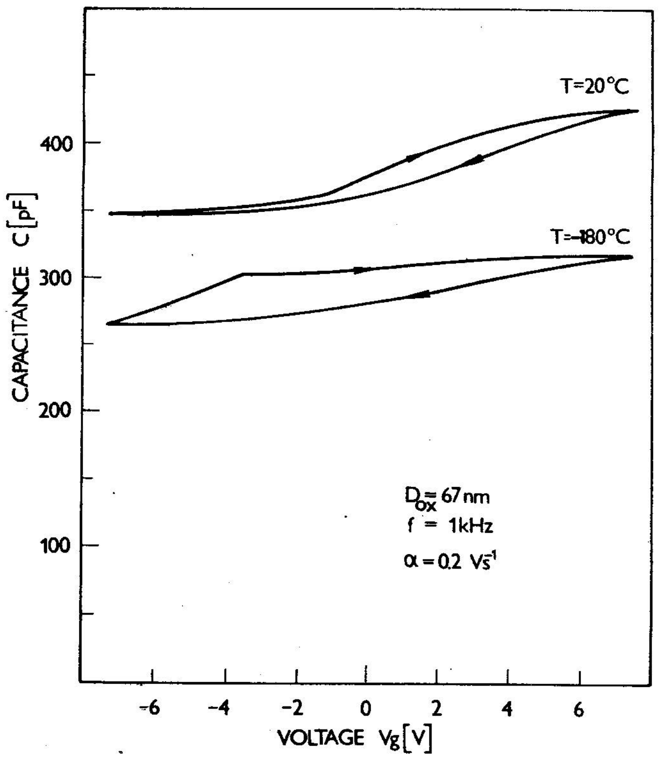

Fig. 4. Typical dependence of the capacitance on the bias voltage U_g of the GaAs MOS structures for an oxide thickness of 65 nm.

III.3. Energy spectrum of electron states at the interface between GaAs and the plasma oxide

The pronounced hysteresis of the GaAs MOS structure C-V curves discussed in the foregoing part indicates a considerable density of deep capture centres at the GaAs-oxide interface region. We carried out measurements of the MOS structure response to a voltage pulse to obtain information about the deep level spectrum.

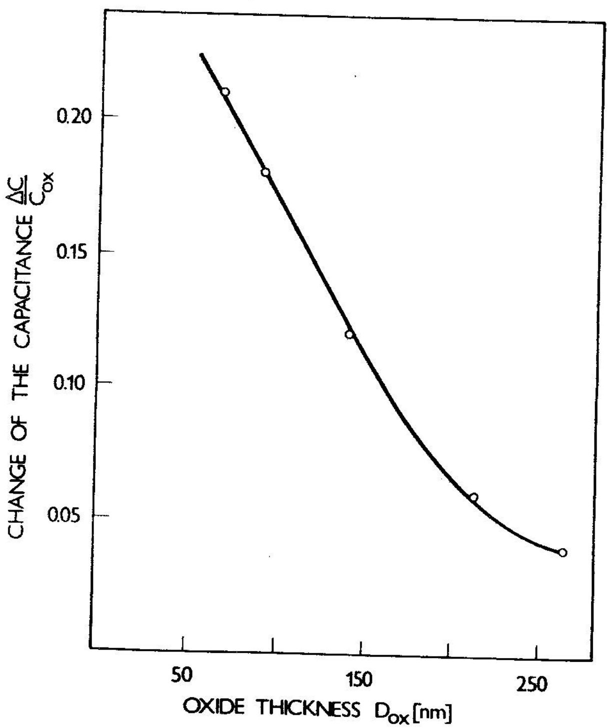

Fig. 5. The relative change of the capacitance between — 180 °C and 20 °C versus the oxide thickness D_{ox} ($U_a = 7$ V).

The response has been measured in the DLTS mode (deep level transient spectroscopy), elaborated by Lang [5]. In regard of the complicated character of the response the excitation by the small voltage pulse $\Delta U = 50$ mV ($\sim 2\,kTq^{-1}$) has been chosen, superimposed on the quiescent potential U_a of the gate. In the case of the sufficiently small ΔU the formula (1) can be written for the charge DLTS as

$$Q = \int_{t_1}^{t_2} i(t, T)\,\mathrm{d}t \simeq \frac{C_0}{C_0 + C_s} A q N_{ss}(E_t) f(t_1, t_2, T) \Delta E_F \qquad (1)$$

where C_0 is the oxide capacitance, C_s is the capacitance of the semiconductor depletion region, A is the gate area, $N_{ss}(E_t)$ is the density of states at the energy E_t, ΔE_F is the shift of the Fermi level in response to the charge of the gate potential ΔU and $f(t_1, t_2, T)$ has the form

$$f(t_1, t_2, T) = [\exp(-t_1/\tau) - \exp(-t_2/\tau)]\,[1 + \exp(-\Theta/\tau)]^{-1}. \qquad (2)$$

Where $\tau = \tau(T)$ represents the time constant of the transient phenomenon at the temperature T and Θ is the voltage pulse duration, which is the same as the interval between the pulses. The typical course of the interface states density, obtained by formula (1), is in Fig. 6.

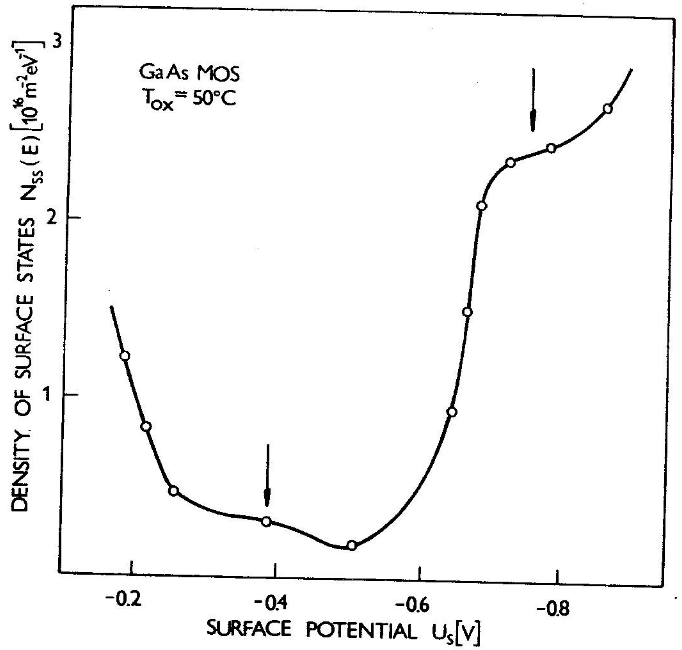

Fig. 6. Dependence of the density of the surface states on the surface potential.

We see the peaks corresponding approximately to the value of the surface potential of the semiconductor $U_s = 0.38$ eV and 0.75 eV, respectively, superimposed on U-shaped continuous spectrum of states. The value qU_s represents approximately the position of the trapping level within the forbidden gap of GaAs if we take into consideration the fact that $E_F \simeq E_C$ in the neutral bulk of the semiconductor. E_C is related to the edge of the GaAs conduction band.

As known from literature [6], the levels E_C — 0.4 eV and E_C — 0.75 eV are characteristics of the GaAs crystal doped with O. In addition, the 0.75 eV level, known as EL2, is responsible for semiinsulating character of the GaAs : O crystals.

IV. CONCLUSION

The interaction of the oxygen plasma with the GaAs surface at the anodic oxidation gives rise to a high resistivity GaAs in the narrow region close to the semiconductor oxide interface. The existence of that interlayer compensated with oxygen is meanwhile the obstacle to using the GaAs plasma anodic oxide as an active layer for the production of the insulated gate field effect transistor for a broad frequency range.

ACKNOWLEDGEMENT

We wish to express our thanks to Mr. Ľudovít Válek for his constant help in the solving of technological problems.

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Received June 8th, 1984
Revised version received September 11th, 1984