INVESTIGATION OF THE INTERFACE STATE DENSITY OF p-Si/ANODIC OXIDE/Al STRUCTURES OBTAINED BY APPLICATION OF VARIOUS CONSTANT VOLTAGES

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In order to study the effect of various constant voltages on the properties of p-Si/ anodic oxide (AO) interface, metal-oxide-semiconductor capacitors (MOSC) have been used. Anodic oxide films were grown under various constant voltage conditions by using (1:1) v/v aqueous solutions of sodium dihydrogen orthophosphate ($NaH_2PO_4.2H_2O$) and diethylen glycol ($C_4H_{10}O_3$). MOS structures have formed by coating of Al under high vacuum conditions onto the prepared anodic oxide layer. The small signal capacitances of MOS were measured as a function of the bias at room temperature. The experimental surface state density was calculated by means of the theoretical $C-V$ curves. The surface state densities of MOS structures with anodic oxide layer prepared in various constant voltages were compared with each other. We have observed that the surface state density curves obtained in this study was closer the ideal curve.

1. INTRODUCTION

Semiconductors have application to a wide variety of high–frequency (HF) MOS devices. Metal-oxide-semiconductor (MOS) elements are widely used as the base of the circuit elements in various semiconductor [1]. The fabrication of such devices depends on both a good insulating oxide and a low interface state density (ISD) at the oxide layer and semiconductor interface [2-5]. The thermal oxide affects the homogeneity of injection atoms in interface area [6]. This problem does not appear in films obtained by anodic oxidation. Recent studies on very thin anodic SiO_2 films have indicated that anodic oxide films are homogeneous and uncontaminated [7].

We investigated the $C-V$ characteristics and the distribution of anodic p-Si MOS structures prepared by using (1:1) v/v aqueous solutions of sodium dihydrogen orthophosphate ($NaH_2PO_4.2H_2O$) and diethylen glycol ($C_4H_{10}O_3$) electrolyte with a pH of 5.35 at four different constant voltages as a) 30 b) 40 c) 50 and d) 60 V/cm^2.

2. EXPERIMENTAL PROCEDURE

Si/AO/Al structures were prepared on (100) oriented, 8.10^{14}cm^{-3} doped p-type Si substrates with a resistivity between 14 and 26 Ω-cm and one of the (100)-faces were mechanically polished. The doping concentration has been determined from the deep depletion of $C-V$ curves (from the $C^{-2}-V$ curves) of the MOSC. Back ohmic contacts were provided by the alloying with Al. Then, the wafer was divided into four groups of samples on which the oxide layer was to be formed by the anodization electrolyte. Before anodization, the samples were treated in HF:H_2O (1:15) solution to remove all traces of oxide on the surface to be anodized, and they were rinsed with deionized water. The side with the ohmic contact and the edges of the p-Si were carefully covered by wax and then the polished front sides of the samples were exposed to the electrolyte by attaching the equipment employed for the anodized in (1:1) v/v aqueous solutions of so-

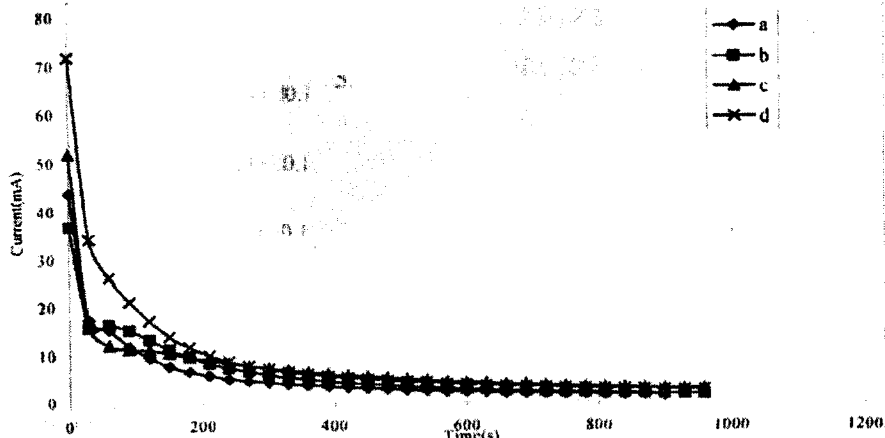

Fig.1.

dium dihydrogen orthophosphate ($NaH_2PO_4.2H_2O$) and diethylen glycol ($C_4H_{10}O_3$) electrolyte with a pH of 5.35 at four various constant voltages of 30, 40, 50 and 60 V/cm^2 and at room temperature and under room light. The current–time ($I-t$) curves for four various constant voltages and a pH of 5.35 are given in Fig.1. Aluminium dots of 1.0 mm in diameter were evaporated onto the oxide layer. Thus, Al/anodic oxide film/p-Si/Al MOS structures were obtained. All evaporation processes were carried out in a vacuum coating unit at about 10^{-5} Torr.

The small signal ac capacitance measurements as a function of applied voltage ($C-V$) at 100 kHz were made with HP 4192A 5Hz–13 MHz LF impedance analyser. The HF $C-V$ measurements of the anodic MOS structures were carried out at room temperature and at 100kHz in the range from +0.5 to –3.5V.

3. RESULT AND DISCUSSION

Hysteresis in MOS structures can be caused either by ion (such as Na^+, K^+ or H^+) movement from / to the silicon / oxide to / from the metal / oxide interface through the oxide bulk or trapping / detrapping of electrons / holes from the silicon bands to defects in the oxide near the silicon / oxide interface. The two mechanisms give rise to hysteresis in opposing directions. In the case of the mobile ion movement, the response time to bias stressing is the sum of times for detrapping at the interface and drift through the bulk oxide [8]. If the voltage shift is negative for positive bias stressing and positive for negative bias stressing, the hysteresis is caused by the movement of mobile ions through the oxide bulk. On the other hand, if the voltage shift has the same sign as that of the bias stressing, then the event involved is the exchange of electrons/ hole between the silicon energy bands and oxide traps close to the oxide/ silicon interface [8].

The capacitance-voltage ($C-V$) characteristics of the samples measured at 300 K is shown in Fig. 2. The HF $C-V$ ideal

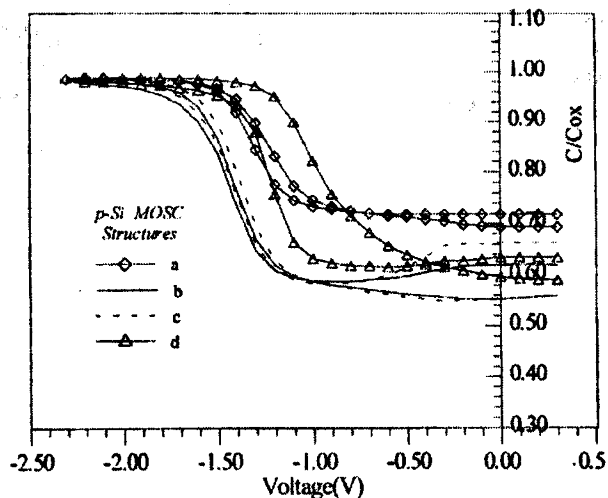

Fig.2.

curves of the samples are not shown here. All of the $C-V$ curves showed shifts to the left in comparison with the ideal curves. By the comparison of our $C-V$ curves in this study with the results of the D.Landheer et al. [9] who studied the anodic oxide grown onto silicon under constant voltage condition, it was observed that the $C-V$ curves of these authors shifted left more than our $C-V$ curves. These shifts indicate that the grown anodic oxide films contain fixed positive oxide charges [10], which can be determined by the equation

$$\Delta Q_{ox} = \Delta V_{FB} C_{OX} / q \quad . \qquad (1)$$

By using this equation, the fixed oxide charge concentrations (ΔQ_{ox}) have been calculated for all the $C-V$ curves of the samples and given in the Table The sample (a) had the smallest oxide charge concentration.

Table. The values of the interface and the hysteresis state densities for all samples at 100 kHz, 300 K

Samples	a	b	c	d
ΔQ_{ox} (cm^{-2})	39.66×10^{11}	78.12×10^{11}	76.72×10^{11}	51×10^{11}
ΔQ_{ss} (cm^{-2})	11.22×10^{11}	17.34×10^{11}	15.89×10^{11}	9×10^{11}
N_{ssmax} (cm^{-2}eV)$^{-1}$	46.87×10^{12}	36.8×10^{12}	6.12×10^{12}	99.6×10^{12}

It has been observed that all the $C-V$ curves showed hysteresis behavior; the samples a, b and d, ionic type hysteresis and the sample c carrier injection type hysteresis. The calculated charge densities are given in the Table. The carrier injection type hysteresis exhibited from the traps in the grown oxide film. The ionic type hysteresis of sample indicates that the anodic oxide films grown in the electrolyte contain mobile ions. For MOS structures, unstable behavior due to mobile ions in the structures, especially hysteresis with ionic character is also desirable.

In order to examine the silicon / anodic silicon oxide interface properties, the variation of the interface state density in the band gap was calculated by comparing the ideal $C-V$ curves and the curves measured by the Terman high frequency method [11]. The results are shown in Fig. 3.

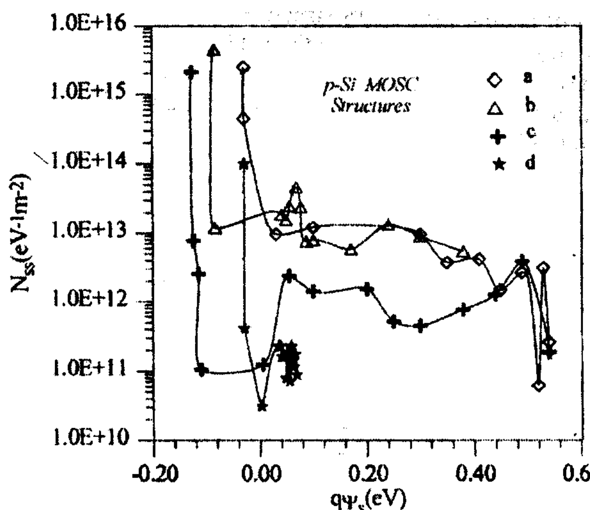

Fig.3.

According to the Terman method [11], used to calculate the interface state density, for every experimental point in the graps, the voltage shift, ΔV_G, was determined for the same

value of capacitance between the experimental curve and ideal curve. By using the equation

$$\Delta Q_{SS}=C_{OX}\Delta V_G/A_{OX} \quad , \qquad (2)$$

the surface charge was calculated. This charge was drawn as a function of interface potential. The interface state density was calculated from the slope of the curve $Q_{SS}(\psi_s)$. The interface state density was found as approximately 10^{12}/eVcm^2 in this study. At the same time, it was observed that the interface state density curves obtained in this study was closer the ideal curve [12].

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p-Si/ANOD OKSİDİ/ Al STRUKTURUNUN TƏMAS SƏRHƏDDİNDƏ HAL SIXLIĞININ TƏTBİQ EDİLƏN SABİT GƏRGİNLİKDƏN ASILILIĞININ TƏDQİQİ

Müxtəlif sabit gərginliklərin, tə'sirinin p-Si/anod oksidi strukturunun/ təmas sərhəddinin xassələrinə tə'sirini tədqiq etmək üçün, metal-oksid yarımkeçirici kondensatorlardan istifadə edilmişdir. Həcmi nisbəti 1:1 olan, $NaH_2PO_4 \cdot 2H_2O$ və $C_4H_{10}O_3$ maddələrinin su məhlulundan istifadə edərək, sabit gərginliyin tə'siri şəraitində anod oksidi təbəqələri alınmışdır. MOY strukturları, hazırlanmış anod oksidinin üzərinə, yüksək vakuum şəraitində, Al-un çəkilməsi vasitəsilə əldə edilmişdir. MOY tutumların zəif siqnalları otaq temperaturunda yerdəyişmə funksiyası kimi olçülmüşdür. Səthi sıxlığın təcrübi qiyməti, nəzəri C-V əyrilərindən istifadə edərək, hesablanmışdır. MOY- strukturlarının sıxlıqlarının bu qiymətləri bir-biri ilə müqayisə edilirdi. Göstərilmişdir ki, işdə alınmış səthi sıxlıq əyriləri ideal hala yaxındır.

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ИССЛЕДОВАНИЕ ПЛОТНОСТИ СОСТОЯНИЙ НА ГРАНИЦЕ РАЗДЕЛА p-Si /АНОДНЫЙ ОКИСЕЛ/ Al СТРУКТУР В ЗАВИСИМОСТИ ОТ ПРИЛОЖЕННЫХ ПОСТОЯННЫХ НАПРЯЖЕНИЙ

Для изучения влияния различных постоянных напряжений на свойства границы раздела p-Si /анодный окисел/ были использованы металло-окисные полупроводниковые конденсаторы. Анодные окисные пленки были выращены в условиях приложенного постоянного напряжения с использованием водного раствора $NaH_2PO_4 \cdot 2H_2O$ и $C_4H_{10}O_3$ в объемном соотношении 1:1. МОП-структуры были приготовлены нанесением Al на подготовленный слой анодного окисла в условиях высокого вакуума. Слабые сигналы МОП-емкостей были измерены как функция смещения при комнатной температуре. Экспериментальное значение плотности поверхностного состояния было вычислено с помощью теоретических C-V кривых. Эти значения плотностей МОП-структур сравнивались друг с другом. Показано, что кривые плотностей поверхностного состояния, полученные в работе, близки к идеальным.

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