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Frequency dependent dielectric properties of PMMA deposited on p-type silicon

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ABSTRACT

Al/Poly(methyl methacrylate)(PMMA)/*p*-Si organic Schottky devices were fabricated on a *p*-Si semiconductor wafer by spin coating of PMMA solution. The frequency and voltage dependent dielectric constant of Al/PMMA/*p*-Si have been investigated. Dielectric properties and electrical conductivity of Al/PMMA/*p*-Si structure have been investigated in detail by using experimental *C–V* and *G–V* measurements in the frequency range of 30 kHz–1 MHz and voltage from −4 V to 4 V. The frequency and voltage dependent dielectric constant ε', dielectric loss ε'', tangent loss (tan δ), electrical modulus (M' and M''), and ac electrical conductivity σ_{AC} properties of Al/PMMA/*p*-Si structure have been investigated in the various frequencies at room temperature. It can be concluded that the interfacial polarization can be more easily occurred at low frequencies, and the majority of interface states at metal–semiconductor interface, contributes to deviation of dielectric properties of Al/(PMMA)/*p*-Si structures.

1. Introduction

Organic materials that can also be applied in flexible electronic products include backplane circuitries, which can be used for the fabrication of bendable displays for electronic paper and flexible computers [1,2]. The development of small molecules and polymeric materials with high performance is fundamental to the progress of organic thin-film transistors (OTFTs) based electronic technologies [3–8]. While tremendous efforts have been focused on increasing the mobility of organic materials for better device performance, an alternative approach is to enhance the dielectric properties of the gate insulators while maintaining easy processability and flexibility of the dielectric materials. Poly (methyl methacrylate) (PMMA) is one of the promising polymeric materials and there are numerous papers for its application as a gate dielectric in organic thin film transistors (OTFTs) [9–11]. PMMA's thermal and mechanical stability, together with its high electrical resistivity ($>2\times10^{15}$ Ω cm), suitable dielectric constant and thin film processability on large areas by spin coating make it an ideal candidate as a dielectric layer in organic electronics. Optical, electrical and micro-gravimetric properties of PMMA thin films are used to investigate the chemical sensing capability. This is a thermoplastic volatile organic compound material with good tensile strength and hardness, high rigidity, transparency, good insulation properties, excellent planarity and thermal stability dependent on tacticity [12-19]. PMMA's disadvantages such as brittleness and low chemical resistance can be eliminated by chemical or physical modifications.

Metal–semiconductor (MS) contacts are fundamental devices in the technology of semiconductors. It is well known that interface properties of MS contacts have a dominant influence on the device performance, reliability and stability [20,21]. Similarly, the electrical properties of the

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MS contacts could be increased by means of the selection of a proper organic material. In this respect, the interfacial parameters such as the density of interface states and the thickness of interfacial layer can influence both the electrical and the dielectric behavior of these structures [22–29]. It is known, when localized interface states exist at the interface, the device behavior is distinct (different) from the ideal case. Since the interface capacitance (excess capacitance) depends strongly on the frequency and applied voltage, the $C-V$ and $G-V$ characteristics are strongly affected [22–32]. The frequency response of the dielectric constant (ε'), dielectric loss (ε'') and loss tangent ($\tan\delta$) is dominated by a low frequency dispersion, whose physical origin has long been in question [28,33,34].

In the present paper novel Al/PMMA/*p*-Si structures with small area were investigated at both the forward and reverse bias admittance measurements over the frequency and voltage range of 10 kHz–1 MHz and −4 to 4 V at room temperature, respectively. The variation of (ε'), (ε''), ($\tan\delta$), ac electrical conductivity (σ_{AC}) and real and imaginary part of electric modulus (M' and M'') have been investigated as a function of frequency and voltage.

2. Experimental

In this work, the samples were prepared on a *p*-type Si (111) wafer which had 280 μm thickness and 10 Ω cm resistivity. Before processing the wafer, cleaning procedures were applied. Firstly, it was dipped into acetone for 10 min at 50 °C. Then, it was washed by deionized water and released into methanol for 2 min. Again, the wafer was washed by deionized water and inserted into NOH_4:H_2O:–H_2O_2 solution for 15 min at 70 °C. It was dipped into deionized water to remove the solution on the wafer surface. In order to take away free oxygen on the surface, the wafer was bathed in 2% hydrofluoric acid (HF) solution for 2 min. Finally, deionized water was used to complete the cleaning procedure. After this chemical cleaning procedure, the wafer was put into a vacuum chamber where Al (99.999%) was evaporated on the unpolished surface as ohmic contact with a thickness of 1240 Å. Then, the wafer was annealed at 500 °C in vacuum for 10 min to dope aluminum into the back surface of the wafer. Again, the back surface of the wafer was coated by Al 1240 Å to complete ohmic contact. The PMMA (950 PMMAC2 MicroChem) was diluted in chlorobenzene (PMMA: chlorobenzene = 1:7). The PMMA layer was constructed by the spin coating technique. The film was deposited by spin coating at 5000 rpm for 45 s on the polished surface of the wafer and was baked on a hot plate at 180 °C for 60 s to drive off the solvents. After spin coating the wafer, 1280 Å-thick Al circular rectifying contacts, 1.3 mm in diameter, were deposited by evaporation at 2×10^{-6} Torr. *C*–*V* and *G*–*V* measurements were taken at room temperature to determine the dielectric characteristics of the Schottky diode. The schematic representation of the device is shown in Fig. 1. The thickness of the oxide layer was 10 nm which was evaluated from an ellipsometer.

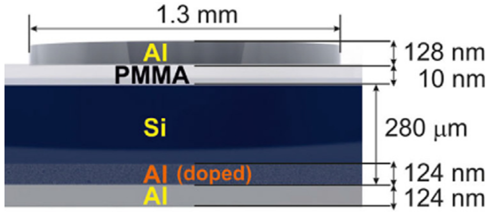

Fig. 1. Schematic representation of cross-sectional front view of Al/PMMA/*p*-Si Schottky diode for electrical characterization.

3. Results and discussion

In the generalized model of the metal–semiconductor contact, a thin dielectric interface layer and surface states must be taken into account. In that case, applied voltage is distributed between dielectric layers, depletion layer and recharged surface states [30]. The metal–semiconductor contact, being the capacitor, is also characterized by dielectric losses. The shift of phases between action factor and reaction factor of contact can be caused by the inertia of charge carriers, which are transferred through depletion layer, recharging of surface states. Under Maxwell–Wagner's theory interlayer polarization is the accumulation of a charge on the interface of layers, having various values of the conductivity. Such polarization results in the change in the intensity of an electric field in layers. An interlayer polarization is characterized by a relaxation. The time of a relaxation is defined by layer parameters such as conductivity, dielectric permeability and thickness [28].

The capacitance, dielectric constant and electric modulus are important parameters in the selection of materials for device application. From the values of capacitance and conductance of Al/PMMA/*p*-Si Schottky diode in the frequency range of 30 kHz–1 MHz, applied voltage dependence of (ε'), (ε''), ($\tan\delta$) and (σ_{AC}) of PMMA/*p*-Si interfaces are determined. The real part of dielectric constant shows the capacitive behavior or polarizability of the material, while the imaginary part shows the energy losses due to polarization and conduction. It is known that the high-frequency electrical properties of Schottky devices at accumulation mode describe basically the dielectric properties of the bulk organic interfacial layer. Dielectric relaxation and electric modulus behavior of the heterojunction were determined by means of the measured capacitance and conductance. The complex permittivity can be written [28,31,34,35] as follows:

$$\varepsilon^* = \varepsilon' - i\varepsilon'' \tag{1}$$

where ε' and ε'' are the real and imaginary parts of complex permittivity, respectively, and i is the imaginary root of −1. The complex permittivity formalism has been employed to describe the electrical and dielectric properties. The values of the real ε' and imaginary ε'' dielectric constant in the frequency range from 30 kHz to 1 MHz can be calculated from [28,35]

$$\varepsilon' = \frac{C}{C_0} = \frac{Cd_p}{\varepsilon_0 A} \tag{2}$$