Preparation and Characterization of MOS Device using MgO Film as A Dielectric Material

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Abstract

In the present work, fabrication and characterization of Al/MgO/Si MOS device has been carried out using PLD as a deposition technique, and for comparison Al/SiO2/Si MOS device has been also constructed. The obtained result show that , The Electrical and photovoltaic characteristics of MOS device are strongly dependent on the oxide type and thickness, beside that, the C-V measurement reveled that prepared device are of abrupt type. The Spectral Responsivity measurement of (Al/MgO/Si) MOS device is found to be 0.27A/W while of (Al/SiO_2/Si) MOS device is 0.20A/W and the Rise and Response time measurement of (Al/MgO/Si) MOS device was shorter than of (Al/SiO_2/Si) MOS device.

Keywords: MgO thin film, MOS device, PLD technique,electrical and photovoltaic technique.

تحضير ودراسة خصائص غشاء اوكسيد المغنيسيوم باستخدام تقنية لترسيب بالليزر النبضي

الخلاصة

في هذا البحث ، تم صنيع ودراسة خصائص نبيطه نوع (MOS) (Al/MgO/Si) باستخدام تقنيه الترسيب بالليزر النبضي ، ولاجل المقارنه تم تصنيع نبيطة من نوع (Al/SiO2/Si (MOS)) ، اضهرت النتائج التي تم الحصول عليها ان الخصائص الكهربائية والبصريه للنبائط المحضره تعتمد بصوره كبيره على نوع الاوكسيد المستخدم ،كذلك اظهرت خصائص سعة –جهد ان النبائط من النوع الحاد . خصائص الاستجابية الطيفية للنبيطه نوع(Al/MgO/Si) كانت حوالي0.27A/W بينما للنبيطه الثانيه نوع (Al/SiO_2/Si) وجدت لتكون0.20A/W اما نتائج زمن النهوض فبينت ان زمن النهوض للنبيطه نوع (Al/MgO/Si)اقصر من مثيلة للنبيطه نوع (Al/SiO_2/Si).

Introduction

Magnesium oxide is a material that has low dielectric constant and low refractive index. It is also thermally stable and highly ionic insulating crystalline solid [1]. Since the invention of the first three- terminal device by Jhon Bardeen and Walter Brittain in 1984, the solid- state electric industry has experienced rapid growth over lower decades. Metal- Oxide- semiconductors (MOS) Device were first proposed in the sixteenth century and attracted considerable attention due to their simplicity [3]. Soon after the perfection of the Si- SiO2 interface and the development of integrated

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technologies, MOSFETS becomes the devices in the silicon- based semiconductor industry, Historically, device scaling, quantified by Moor's law, has driven MOS integrated circuit technologies. Decreases in device featured size have decreased at the rate of about 70% every three years for most of the industry's history- cost per function has simultaneously decreased at an average rate of about 25-30% year/ function .One of the most important reason beyond which we looking for new dielectric oxide layer in the MOS devices is the scaling restrictions [2,3]. One fundamental restriction to the scaling of MOS structure has been photolithography, which defines the smallest feature size, i.e. the channel length (L). For devices of channel length comparable to the depletion regions around the source and drain, short- channel effects associated with charge- sharing and punch- roogh are intolerable. Thus, to make L small, the depletion region widths have to be reduced by using a heavily doped substrate and a lower supply voltage. At the same time, silicon oxide thickness needs to be reduced to balance the threshold voltage increase that is induced by higher substrate doping concentrations [3-5]. In figure (1) MOS transistor obtained by scaling all geometrical dimensions by the same factor, α, is illustrated the idea behind this scaling is to the electric field unchanged in a short-channel device in order to maintain comparable characteristics and reliability relative to along channel device. Among all the materials for MOS devices, the gate Oxide remains one of the most critical, since it plays a fundamental role in the concept of "field effect" control. Thermally grown Oxide (SiO2) has been used as a gate dielectric since MOSFET Devices were first introduced due to its process simplicity, nearly perfect insulator properties, and compatibility with the silicon substrate. However, the phase- out of SiO2 is needed as early as the 100nm node due to a number of issues including high leakage currents and inadequate reliability for a SiO2 dielectric layer less than 1.5nm thick. It has been well documented that it will be difficult if not impossible to use SiO2 in this thickness regime Extensive research is under way to meet the challenge of moving beyond the SiO2 area, i.e. to replace the traditional silicon dioxide / dual- doped polycrys- talline silicon gate stuck process with high- K gate dielectrics and new gate electrode materials, The capacitance, C, of a MOS capacitor is given by [3].

$$K\varepsilon_o A/t_{ox}=K_{SiO2}\varepsilon_o A/t_{ox}^{eq} \quad \text{.....(1)}$$

Where k is gate oxide dielectric constant, ε_o the permittivity of vacuum, A the capacitor area, and t_{ox} gate oxide physical thickness. By assuming the same capacitance is achieved using SiO_2 as the dielectric, the equivalent oxide thickness, eq t_{ox}, is given by.

$$t_{ox}^{eq}=t_{ox}K_{SiO2}/K \quad \text{..... (2)}$$

Which means a thicker gate oxide of high permittivity (which will keep the current leakage current low) can hold the same gate capacitance as a thinner SiO_2 dielectric. Among the ferroelectric oxide film, MgO film have attracted attention for use in the fabricating of high speed switching devices and high frequency devices due to their highly ionic, chemically stability and low dielectric constant properties. MgO transparent oxide has been found to be an alternative dielectric to silicon dioxide (SiO_2) to reduce the electric field in capacitive network [4]. The lattice constant of MgO is 0.421nm and its refractive index and dielectric constant are 1.72 and 9.83 respectively. Magnesium oxide seems to be a good candidate regarding its bulk properties: large band gap (7.8eV), high thermal cond- uctivity and stability the most important challenge in using MgO for MOS device is the lattice mismatch of about 22% by directly deposition on silicon. This problem has been solved by several researchers, for example an amorphous SiO_2 oxide layer is still observed at the MgO/ Si interface, as reported by Tonglai Chen et al because Si will be oxidized by the residual Oxygen during the pumping down of the system and substrate heating which play an important rule in the reducing of lattice mismatch at the interface between MgO and Si substrate [6].

Experiments

Two type of MOS devices have been prepared in order to get an abvous indication about the prepared device by comparing the obtaind result, A Ripid thermal Oxidation (RTO) of P-type silicon waffer was employed at optimum prep- artion condition of (500 °C ,30 sec) [7] to prepare (Metal – Oxide – S/c) (Al –SiO2 -Si) MOS Device. In the other hand (Al/MgO/Si) (MOS) device was prepared using Reactive pulsed laser deposition of MgO thin film on Si substrate using (1.064µm, 7ns, 0.7J/cm2) Q-switched Nd :YAG laser to the ablation of 99.999 Mg target (Aldrich chemical company) located at 45° angle of incidence, Films were depo- sited at substrate temperature of 150 °C in an oxygen ambient 300 mbar (optimum condition) [8]. The thickness of the MgO thin layer has been decied using equation (2). The electrical ,photovoltaic and detector parameter of both device has been measured.

Results and discussion

The results of the current voltage (I-V) measurements in forward and reveres in dark for AL/MgO/Si and AL/SiO2/Si devices prepared at optimum conditions are shown in figure (2). These characteristics are very important to describe the device performance and all device parameters depending on it. In the following curves, the I-V characteristics were given for two devices at optimum conditions under reverse bias (part (a)). It is clear that the curve contains two regions: the first is the generate region where the reverse current is slightly increased with the applied voltage and this tends to generation of electron-hole pairs at low bias. In the second region, a significant increase in the reverse bias can be recognized. In this case, the current resulted from the diffusion of minority carriers through the junction. From the obtained result it is clearly that the current produce by Al/MgO/Si is less than that obtained from the traditional one which is related to the large junction resistant which reduces the leakage current. The results in the figure (2)(b) give the I-V characteristic behavior of the Al/MgO/Si and Al/SiO2/Si device in the forward bias. Two regions are recognized; the first one represents recombination current the first current established when the concentration of the generated carrier be larger than the intrinsic carrier concentration (ni), i.e. ($n*p>ni2$),which lead to recombination process for mass low applicable . The second region at high voltage represented the diffusion or bending region which depending on series resistance and in (MOS) case represented the tunneling region. From the comparison between the results obtained for both devices prepared at optimum condition, we recognized the values of the current improved for second case due to presence MgO layer which increase the depletion region width. The ideality factor n of both devices was estimated [11] at the optimum conditions and found to be (1.3 and 1.1) respectively. These values refer to good rectification properties for both prepared devices. The higher rectifying properties for traditional MOS related to the less lattice mismatch between SiO_2 and Si compared to that between MgO and SiO_2. For the second case beside the presence of some defect in the additional oxide layer thickness like pinhole and other which play an important rule in the ideality factor of the device.

Figure (3) (a,b) gives the C-V and $1/C^2$-V measurements for both device respectively. Results show that the device capacitance is inversely proportional to the bias voltage. The reduction in the device capacitance with increasing bias voltage resulted from the expansion of depletion layer with the applied voltage. The depletion layer capacitance refers to the increment in charge per unit area to the incremental charge of the applied voltage. This properly gives an indication of the behavior of the charge transition from the donor to the acceptor region, which was found to be "abrupt" which is confirmed by the relation between $1/C^2$ and reverse bias being a straight line. The improved in value Vbi for (Al/MgO/Si) diode due to interfacial layer MgO and SiO_2 between metal and Si substrate and this produced increase in oxide thickness. According to the capacitance - voltage measurements[10], the effect-tive charge-carrier density (N), built in potential(Vbi) , the width of the depletion layer (W) and total capacitance (CT) for both device are calculated [13] respectively and tabulated in table(1). Figure (4) a, b exhibits the photo electric behavior of the two devices under illumination condition. It is understood that photo electric effect result from light-induced electron-hole generation at the device and particularly at the depilation region of the P-type silicon. Under external reverse bias, depilation region of the device extends and as a result, more incident photons will contribute to the electron-hole pairs generation that takes place in the depletion region. The internal electric field in the depletion region causes the electron-hole pairs to separate from each other and this bias becomes larger with the applied external bias. From the following figure, we can see the increase in the photo-current with increasing incident light intensity, where the large intensity refers to a great number of incident photons and hence large number of separated electron-hole pairs. From this result, we can recognize the enhancement in values of the photo current in (Al/MgO/Si) diode comparing with traditional diode at the same incident light intensity. This is due to the presence of MgO thin layer (antireflection) which acts as built in coating increase the probability of electron-hole pair's separation in the active region .Beside the increment in the depletion layer width which mean a large internal area for carrier separation. That lead to higher photo-current. Figure (5) show the relation between short-circuit current (ISC) and open-circuit voltage (VOC) with the incident photon power of the halogen lamp for both devices. From the obtained result we can recognize the linear relation between ISC and VOC with the incident photo power to reach a maximum value beyond which both values for the two devices tend to saturated and become constant. This occurs due to the total separation of the photo-generated electron –hole pairs. A large difference in the obtained result value can be obviously found comparing it. The higher result obtained for Al/MgO/Si device related to the increasing of the depletion layer width by adding the oxide layer thickness which mean larger area for electron-holl pairs separation and hence larger photo-current .Since Voc is depending on the photo current and also on the oxide layer thickness [14] For both cases the linear behavior of Voc versus incident power refers to good linearity of the prepared device to work as a detector or solar cell. The spectral responsivity represents the ratio between the output generated current to the incident power and it is very important because it specifies the performance range of MOS device if used as a detector.Figure (6) (a, b) gives the responsivity as a function of wavelength for both devices prepared at optimum conditions. These measurements were achieved in the wavelength range from (200-900) nm.

From the given figure, the range of the spectral responsivity could be obtained to find extended from V to NIR region. While the peak of the Reponsivity, to the highly reduction in surface recombination velocity due to the presence of the large band gap additional oxide layer in the (Al/MgO/Si) device. The fast decrease in the responsivity beyond the peak wavelength is due to recombination process in the surface and that in bulk of the material at longer wavelength .At wavelength near the cut off region of silicon the substrate become transparence for all incident wavelength. The largest value of the responsivity obtained in our work found to be (0.27 A/W) for (Al/MgO/Si) MOS device while the corresponding value for traditional MOS don't exceed (0.20A/W). The improvement in the value of responsivity related to the presence of the additional MgO oxide layer with it specific limited thickness which act as built in antireflection coating beside it effect on increase the depilation layer width, which mean large area for electron-holl pairs separation. Also the presence of thin oxide layer reduces the surface recombine -tion process and hence increases the sensitivity to the high energy wave length that absorbed at the surface. So we can obviously recognize spectral shift toward the shorter wave length as shown in figure, where the peak responsivity found to appear at (530nm) for traditional MOS device Figure (7) (a,b) represents the relationship between the wavelength of the incident light and the quantum efficiency (η) of the both MOS device , and because the quantum efficiency (η) function of the responsivity. Therefore the result is related to the spectral responsivity. The maximum value of the quantum efficiency in case (Al/MgO/Si) MOS device is 0.67, while the maximum value of the traditional one is 0.49.The improve in the quantum efficiency (η%) due to decreases in fast combination process at surface and also the high transmittance of the wavelength in visible region achieved by the presence of the MgO layer. Figure (8) (a, b) represents the obtain rise time pulse of the both MOS device at wavelength (840) nm. The idea of the rise time depending on the developing of internal voltage with the depletion region which used to separate the electron-hole pairs resulting from the absorption of the light energy on the device surface. This mechanism take a specific time depended on the device characteristic.And since this time constant is greatly effected by, carrier diffusion time, carrier drifts time from depletion region and finally depletion region capacitance, we can understand the enhancement achieved in the case of AL/MgO/Si MOS device. The values found to be (868 μsec) and(1004 μsec) receptivity. This result gives a clear information about the enhancement achieved in the first case, hence we can recognize the large reduction appear with the rise time .This reelected on the value of the response time achieved which found to be (394,456) μsec for both device receptivity. The small response time in the first case could be related to the long diffusion of the minority carrier appeared in the large oxide thickness case which related directly to the diffusion time of these carrier which reduce the response of the manufactured device.

Conclusions

According to the obtained electrical properties and that have been estimated we could conclude that it directly depended on oxide type and thickness. Also The value of peak response MOS Device was 0.27A/W which is greater than that of traditional MOS Device which found to be 0.20 A/W, while the rise time of Al/MgO/Si found to be shorter.

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Table (1): the obtained results from the C-V measurements

Type of MOS	$V_{bi}(v)$	N (cm^{-3})	w(μm)	$C_T(nF/cm^2)$
Al/MgO/Si	0.6	$2.22*10^{15}$	0.595	68.02
$Al/SiO_2/Si$	0.5	$5.52*10^{15}$	0.345	115

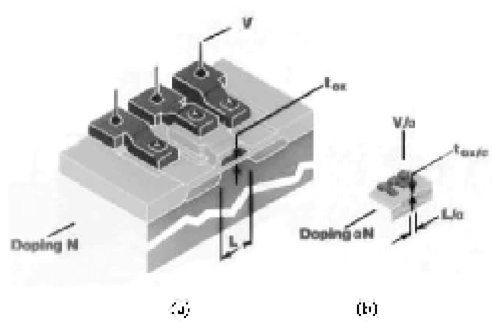


Figure (1): (a) Device dimensions before scaling, and (b) Device dimensions after constant field scaling by a factor a

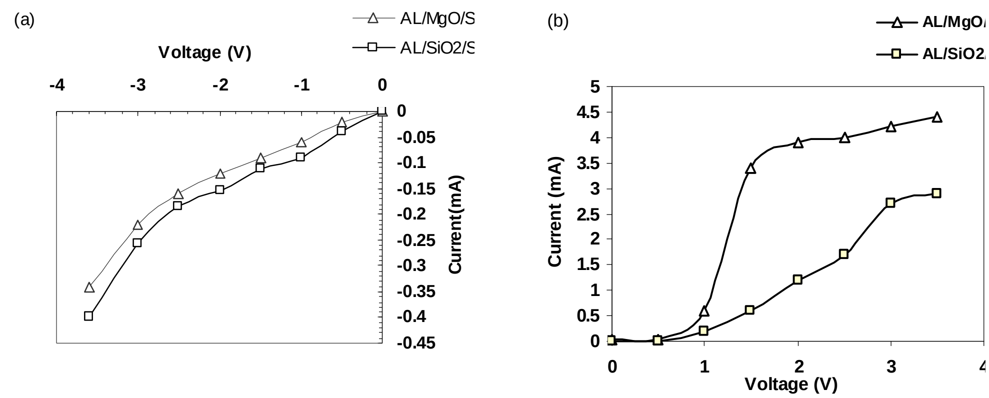
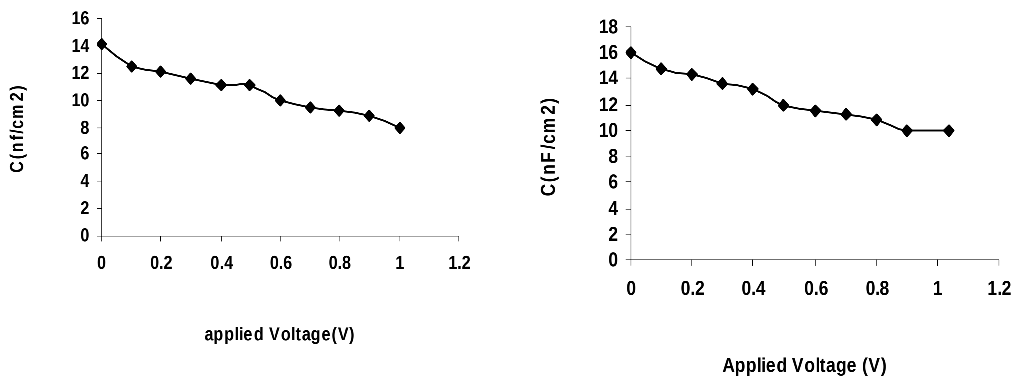
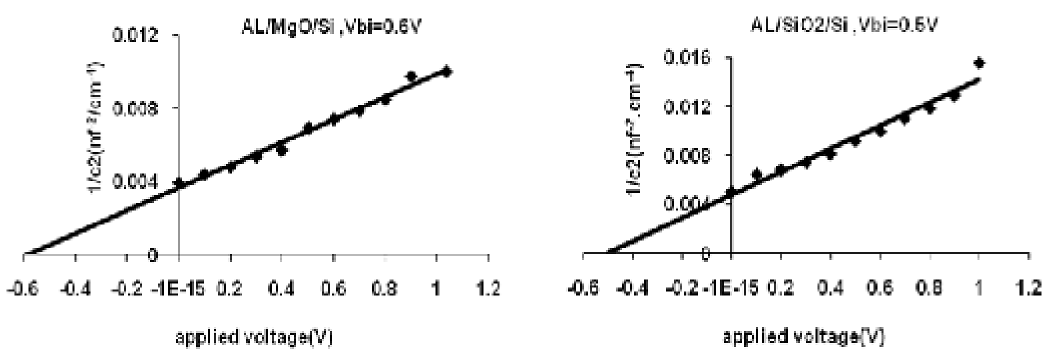


Figure (2)(a,b) I-V characteristic under forward and reverse bias of the both MOS Devices.



(a)



(b)

Figure (3) (a) Junction capacitance as a function of the applied voltage for (b) $1/C^2$ vs. applied voltage for (Al/MgO/Si), (Al/SiO_2/Si) MOS device respectively.

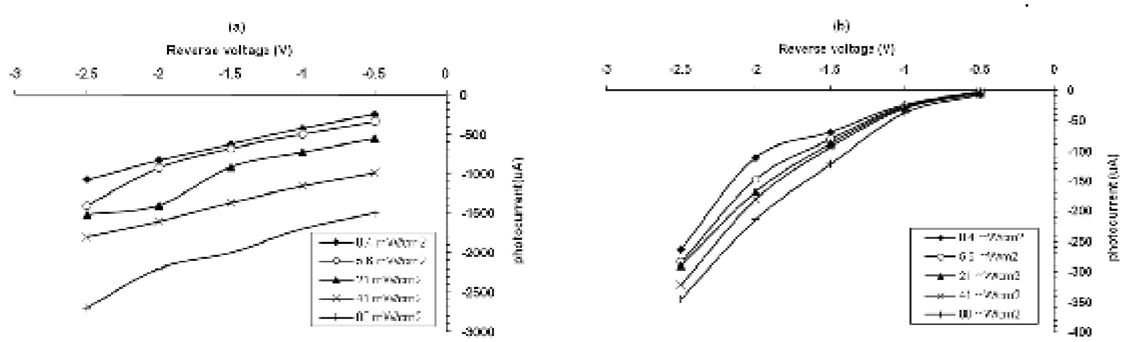
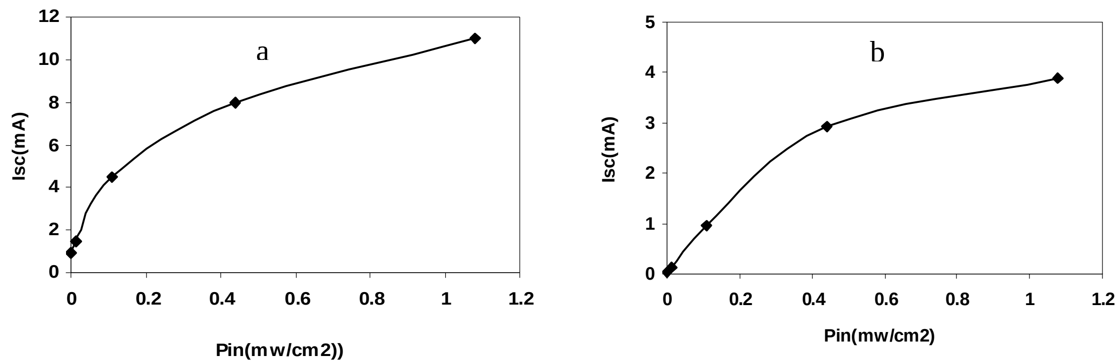
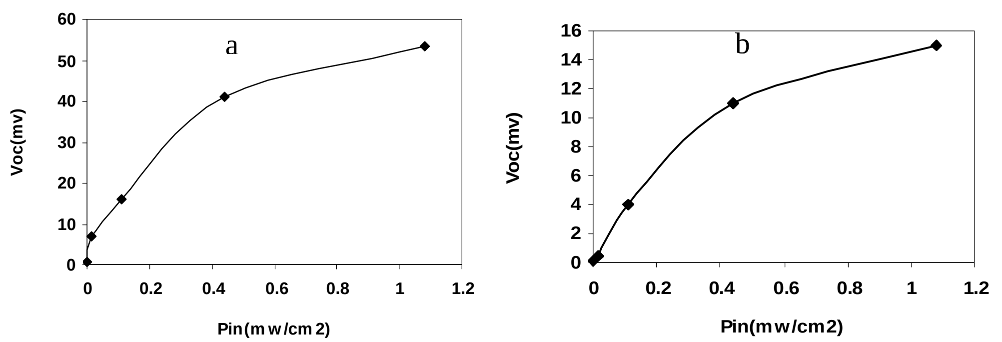


Figure (4): Photo- current as a function of the incident light power density (a) (Al/MgO/Si), (b) ($Al/SiO_2/Si$) MOS device.



(a)



(b)

Figure (5)(a) Short circuit current and (b)open circuit voltage as a function of the incident photo energy for (Al/MgO/Si), ($Al/SiO_2/Si$) MOS devices respectively.

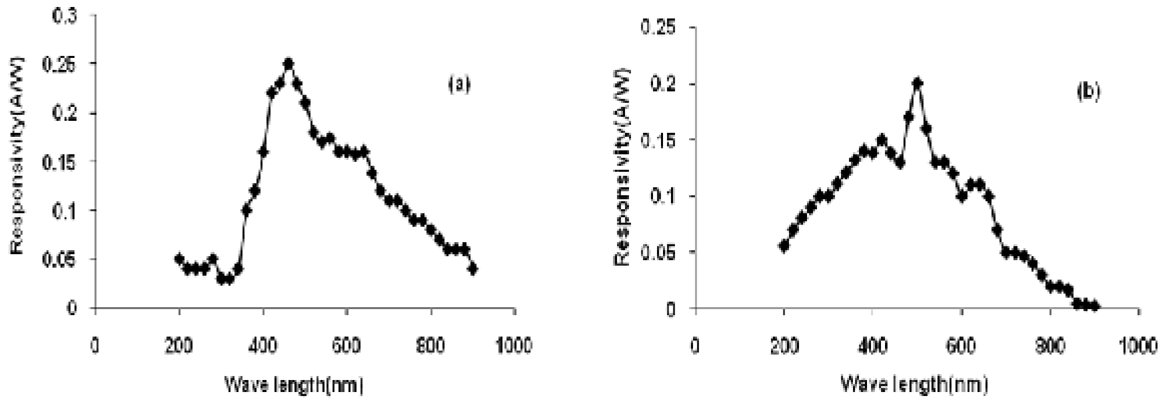


Figure (6): Spectral responsivity as a function of incident photon wavelength (a) (Al/MgO/Si) (b) (Al/SiO_2/Si) devices.

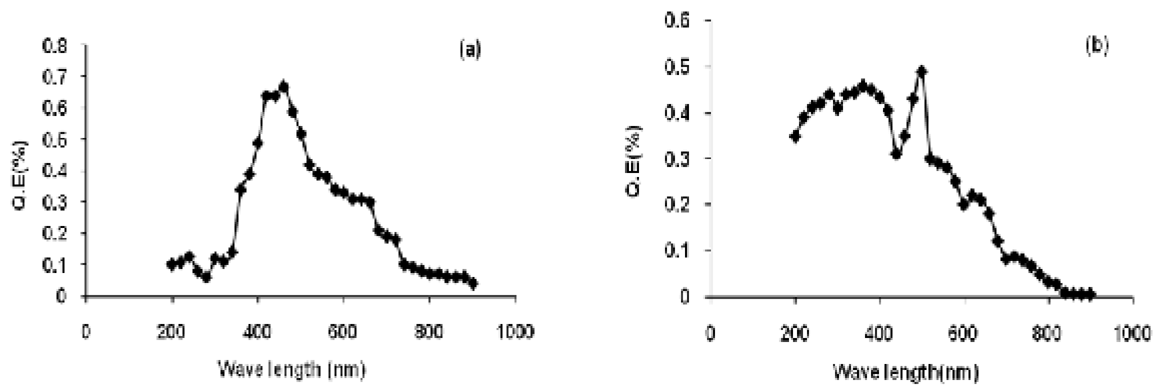


Figure (7): Quantum efficiency as a function of incident photo wavelength (a) (Al/Mg/Si), (b) (Al/SiO_2/Si)

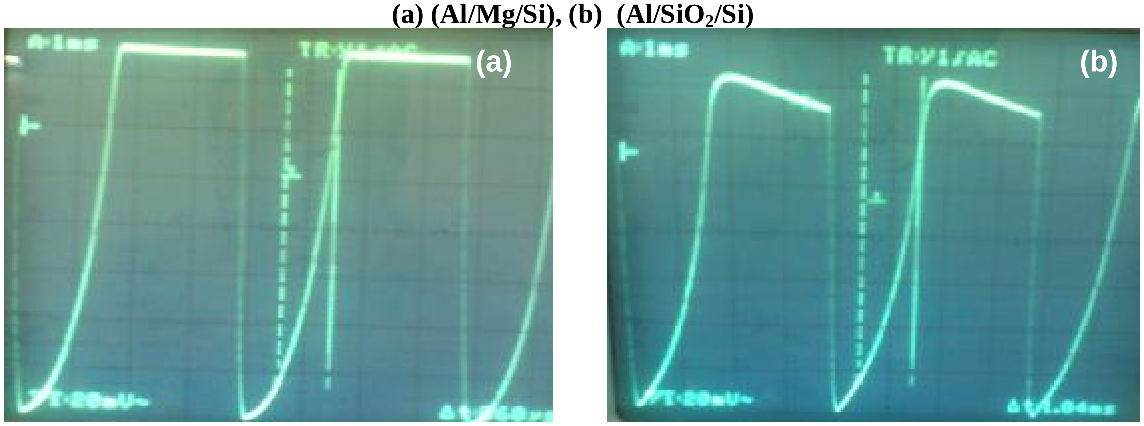


Figure (8): The response time as a function of the rise time (a) (Al/MgO/Si),(b) (Al/SiO_2/Si)