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Growth of Ultra Thick layer of Titanium Dioxide on Silicon Substrate in High Pressure and High Temperature

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Abstract: In this work we are studied that an ultra thin film of titanium dioxide should be a good dielectric gate on silicon substrate. Titanium dioxide film can prevent leakage current and tunneling phenomenon of electrons and diffusion of boron from poly silicon electrode through dielectric gate as well as a silicon dioxide ultra thin film. Considering physical properties of transistors, ultra thin and intermediate films have much more significance. More important difficulties for reducing the dimensions of transistors are the followings: 1- leakage current and tunneling phenomenon of electrons, 2 - diffusion of boron through dielectric gate. Because of these difficulties, using the reduced ultra thin film of silicon dioxide in future nano transistors will be limited. Therefore, a suitable replacement for development of reducing the dimensions of transistors must be finding. Practical aspect of field effect transistors and the thickness of ultra thin film show that titanium dioxide may be a suitable replacement as a dielectric gate.
Keywords: Ultra thin film, leakage current, tunneling, dielectric gate, field effect transistors.

Introduction

Since the years ago silicon dioxide has been applied as dielectric gates in MOS (Metal-Oxide-Semiconductor). When we apply the ultra thin film of silicon dioxide as a dielectric gate, two important phenomena occur: 1- leakage current and tunneling phenomenon of electrons, and 2 - diffusion of boron through dielectric gate. Because of these difficulties, the research has been done for finding a replacement for silicon dioxide. Titanium dioxide has a dielectric coefficient (44) greater than silicon dioxide one (3.8)[1-4]. Then, as a dielectric gate it could prevent the diffusion of light atoms as boron, better than silicon dioxide. This specificity, also, can reduce leakage current about 0.01 time, which is an apparent convenient [5].

Experiments

a) Instruments

1- Ultra sonic bath room, ELMASONIC – E 30 H model.

2- Auger electron spectroscope Perkine Elemer Model.

b) Procedure technique

Setting a layer of titanium dioxide we need very clean surface of silicon substrate. Doing this, we have provided a sample of Si (111) of 10×10 mm and 2 mm thickness. After the cleaning procedure, the sample of Si (111) should be washed by ethanol. Then the sample have brought out of becker and washed with acetone. For advanced cleaning the sample has put in an ultra sonic bath room at 45°C for about 2 hours in Payame Noor University laboratory, while the polished surface was towards top.

The furnace was heated to 1500°C and we have put an alumina crucible with the small pieces of a titanium wire of 0.5 mm of diameter in it for about 1 minute. The large part of titanium wire transfer to vapor and will disperse in extent of furnace. Then the temperature of furnace reduced to 500°C. As this temperature obtained, we have put cleaned silicon sample as quickly as possible in the furnace, while the polished surface was towards top. We wait for about 10 minutes and then very pure oxygen gas was blow into it very preciously and controlled for 25 seconds. After this procedure for thin titanium dioxide film forming, the furnace was cut off and very pure argon gas was blow into it. Then we have let the furnace cooling to ambient temperature in situ. Cooled sample have brought out of furnace and have reserved in a lens paper.

For further discussion on structural properties of this ultra thin film of titanium dioxide, we have studied AES spectrum of the sample so prepared above, by an Auger electron spectroscope Perkine Elemer Model.

Fig. 1 shows an AES spectrum of ultra thin film of titanium dioxide lay on silicon substrate. We can see obviously, silicon, Oxygen and titanium peaks on this spectrum.

The peak in E_k = 280 eV shows carbon impurity which have formed during growing procedure of ultra thin film of titanium dioxide. This impurity should be eliminated by sputtering. Moreover, fig. 1 shows that the amount of oxygen is in excess compared with titanium, which may result in forming silicon dioxide. If SiO_2 dielectric gate considerate as a capacitor, this increases the capacity and consequently may result in leakage current and tunneling phenomena.

Moreover, fig. 2 shows that the amount of oxygen is in excess compared with titanium, which may result in forming silicon dioxide. If SiO_2 dielectric gate considerate as a capacitor, this increases the capacity and consequently may result in efflux and tunneling phenomena.

Fig. 3 shows Sputtering spectrum of titanium dioxide film by Ar^+ ions. This spectrum shows that after removing a few layers carbon will be eliminated.

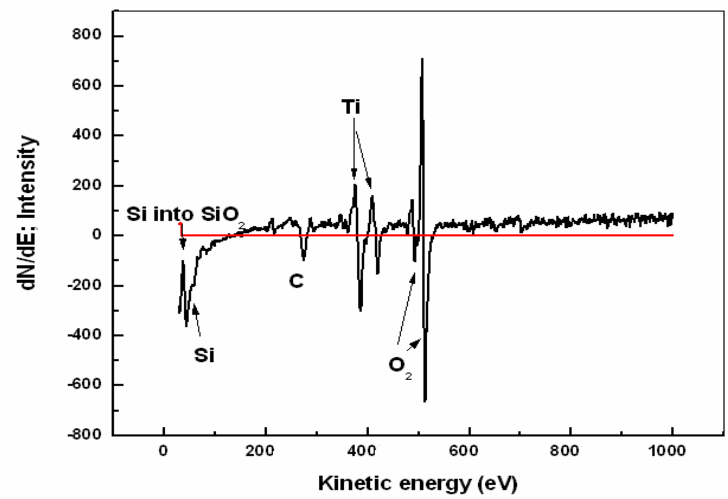

Fig .1. AES spectrum of titanium dioxide ultra thin film.

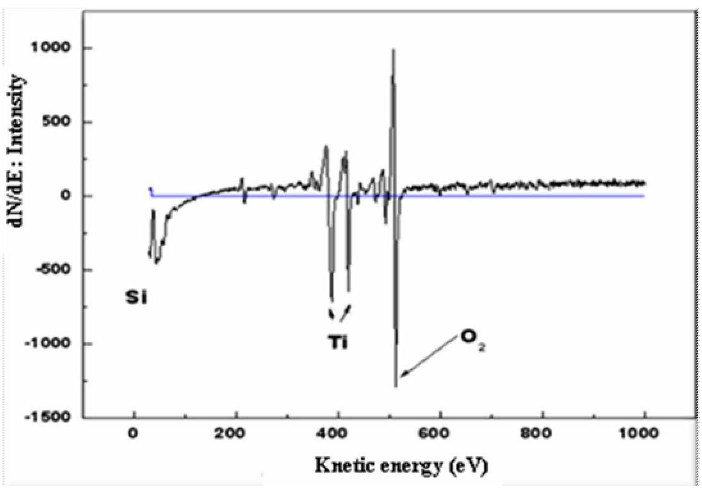

Fig.2. AES spectrum of titanium dioxide ultra thin film, after sputtering by Ar^+.

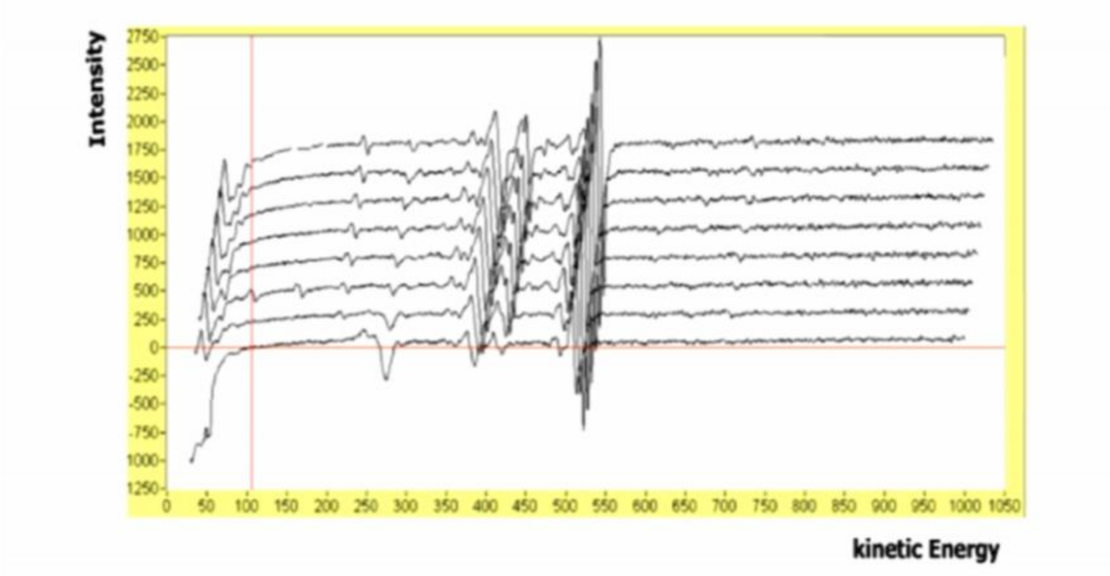

Fig.3. Sputtering spectrum of titanium dioxide film by Ar^+ ions.

c) Results and discussion

AES and Sputtering spectra show the presence of both oxygen and titanium in the film (fig. 3). Evaluating their concentrations ($\mathbf{C_x} = \frac{\mathbf{I_x}}{\mathbf{I_{x.STD}}}$, where I_x and $I_{x.STD}$ are the intensities of element and standard, respectively), may be interpreted by existence of TiO oxide in addition of TiO_2 in oxide film [6 – 11]. This means that there is forming of an amorphous film on silicon substrate, which is able to prevent leakage current and tunneling phenomenon which is suitable in nano transistors [12 – 14].

The excess of oxygen, moreover, may form SiO_2, so that we have both TiO_2 and SiO_2 in intermediate film. In this case, the aspect of intermediate film is so that there are two parallel capacitors and according to $C = C_1 + C_2$, capacity of capacitor increases and the thickness reduces. This may impose some difficulties in using. Whereas presence of carbon in the film of about 2 nano meters of thickness can affect electrical properties and chemical structure of the film and cannot be negligible.

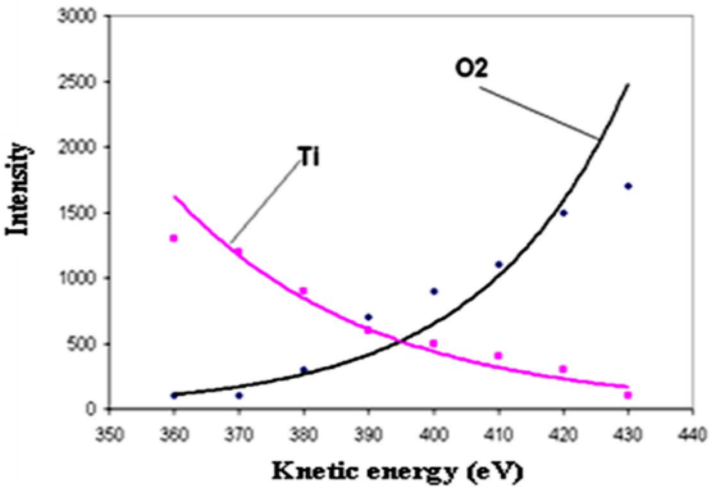

Fig.4. Plots of intensity against kinetic energy of peaks for Ti, Si and O_2

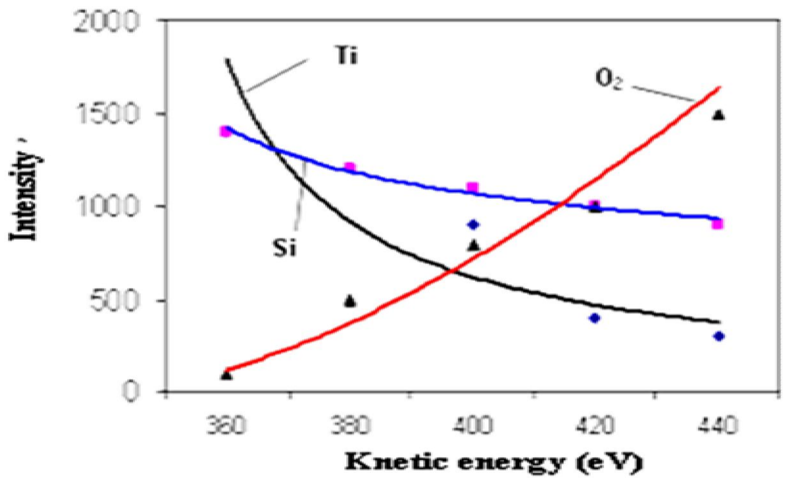

Fig.5. Plots of intensity against kinetic energy of peaks for Ti , O_2 and Si.

Fig.4 shows the plots of intensity against kinetic energy of peaks for Ti and O_2. The figure shows that these two plots intersect each other and this means that at this condition we can grow only the thin film of titanium dioxide. In other terms, in this condition there are not any sites or non completed bonds in titanium atoms for growing more thickly film of TiO_2.

Fig.5 shows the plots of intensity against kinetic energy of peaks for Ti, Si and O_2. This figure shows that at first the plots of Ti and Si intersected this means that firstly there are bonds between Ti and Si atoms. Then by oxygen addition, O_2 molecules pass throughout titanium – silicon film and break down the bonds between Ti and Si atoms and will form the bonds with them.

Conclusion

The structure of obtained thin film of titanium dioxide on silicon substrate is porous and by depositing titanium dioxide on substrate in a longer time, we obtain an approximately uniform film. Carbon impurity may be removed by sputtering method and a pure and clean film should be obtained.

The thickness of film should be obtained by number of sputtering layers (determined by sputtering spectrum) multiplied by velocity 17 Å s^{-1} (obtained by ellipsometery method in this work) and multiplied by the time of sputtering. For our sample, we have obtained the thickness of intermediate film of about 2 nano meter.

Firstly titanium atoms form the bonds with silicon atoms, but by penetration of oxygen molecules through titanium and silicon, titanium dioxide film will form. AES spectrum of this film and the plots of intensity against kinetic energy of peaks for Ti and O_2 show forming both TiO and TiO_2 oxides. Formation of TiO is suitable, because this oxide can prevent leakage current and tunneling phenomenon of electrons and diffusion of boron from poly silicon electrode through dielectric gate.

Moreover, excess of oxygen may form SiO_2, so that we will have the presence of both TiO_2 and SiO_2 oxides in intermediate film.

As silicon dioxide dielectric gate attached to the critical thickness in recent modern transistors[9], we have shown in this work, titanium dioxide film may be applied as a good replacing for SiO_2, in particular, in MOSFSET transistors.

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