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Study the effect of ion type on the transport properties of implanted Tantalum interfaces of multilayer structures

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Abstract:
In this paper, the effect of ion type has been considered to study the transport through the structures. The interfaces of structures have been produced by ion implantation process. The interfaces are Tantalum layers which they have bombardment by Argon and Nitrogen ions. The ion's energy has been considered with energy of 30 keV. The results have been drived t different doses at ambient temperature. In order to study the surface morphology of the ion implanted rough thin films, the atomic Force Microscopy (AFM) analysis has been used. The average roughness has been calculated. Decreasing the transmission probability is the main outcome of the structures rough interfaces. The results show that the interfaces which have been produced by Argon ion implantation are rougher than Nitrogen cases. Moreover in both two cases, the peak to valley ratio reduces. Also, with increasing the Nitrogen ion dose, the current density has been reduced as a function of voltage.

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1. INTRODUCTION

The Tantalum based thin films have been considered in the various field and researches [1], because it has various properties such as high corrosion resistance, mechanical properties, and low density [2-4]. The different experimental and theoretical works show that the Oxygen, Argon, Carbon, and Nitrogen ion implantation improved the surface of tantalum samples [5-6]. The ion implantation process and growth conditions affect the morphology of the implanted interfaces and the mechanical, electrical, and optical produced samples [7-9]. There are many experimental and theoretical rerseraches which they studied the transport properties through Tantalum based thin films [10]. Also, the effect of roughness and the morphology of Tantalum based surfaces have been investigated on the performance of electrical devices [11, 12].

There are various methods to generate the rough interfaces [13]. The effect of rough surfaces/interfaces has been investigated on the structures electrical conductivity [14, 15]. The ion implantation process causes to roughening the resulted interfaces/surfaces [16-18]. Here, the effect of two different types of ions (Argon and Nitrogen) has been investigated on the transport properties of Tantalum based thin films which have been used as the multilayer structures. The transmission probability and current density have been investigated. The paper is organized as follow. In section 2, the materials and experimental details are presented. Measurements and discussions are described in section 3. This section involves two subsections which devote to AFM analysis and the transmission probability and current density of samples have been studied, respectively and the summarized remarks are expressed in section 4.

2. Materials and Experimental Details

In this section the ion implantation process on tantalum samples which done in Plasma Physics Research Center (PPRC), Science and Research Branch, is illustrated. A graphic schemetic of ion implanter is showed in Fig .1. The details of process are as following; the sample which cut into 1 cm × 1cm and 0.58 mm thickness exposed to nitrogen ion implantation. The Nitrogen and oxygen ions lands on sample vertically and their energy and doses of (99.999%) were 30 keV and 1×10^{17} to 10×10^{17} ions/cm^2 at ambient temperature.

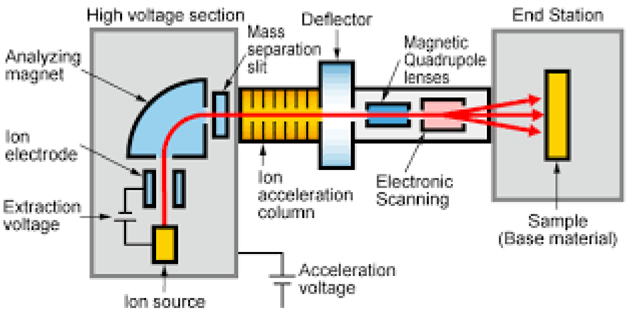


Fig. 1. schematic of ion implanter system.

The ion bombardment which cause to heat transferring, room temperature extended a maximum steady value of 100°C. Because of the range of ions doses, the ion beams cover the entire sample surface uniformly. It is commendable to describe the property of the samples before implantation. In order to have a glossy sample they are polished and then cleaned in alcohol and acetone with ultrasonic system. The extracted nitrogen ions (without mass selection) were accelerated to the maximum energy of 30 keV in the accelerating column and post accelerating prosecco. The nitrogen ions implanted to surface of tantalum samples that placed in normal position with the ion source. During the implantation process, the sample temperature measures with a thermocouple. There are different methods for characterizing the structure and composition of samples. Here, the XRD analysis has been used. The current densities and ion beam energy were kept fixed during implantation process for all samples. The table 1 shows the parameters which are used ion implantation.

Table 1. The parameters of ion implantation process

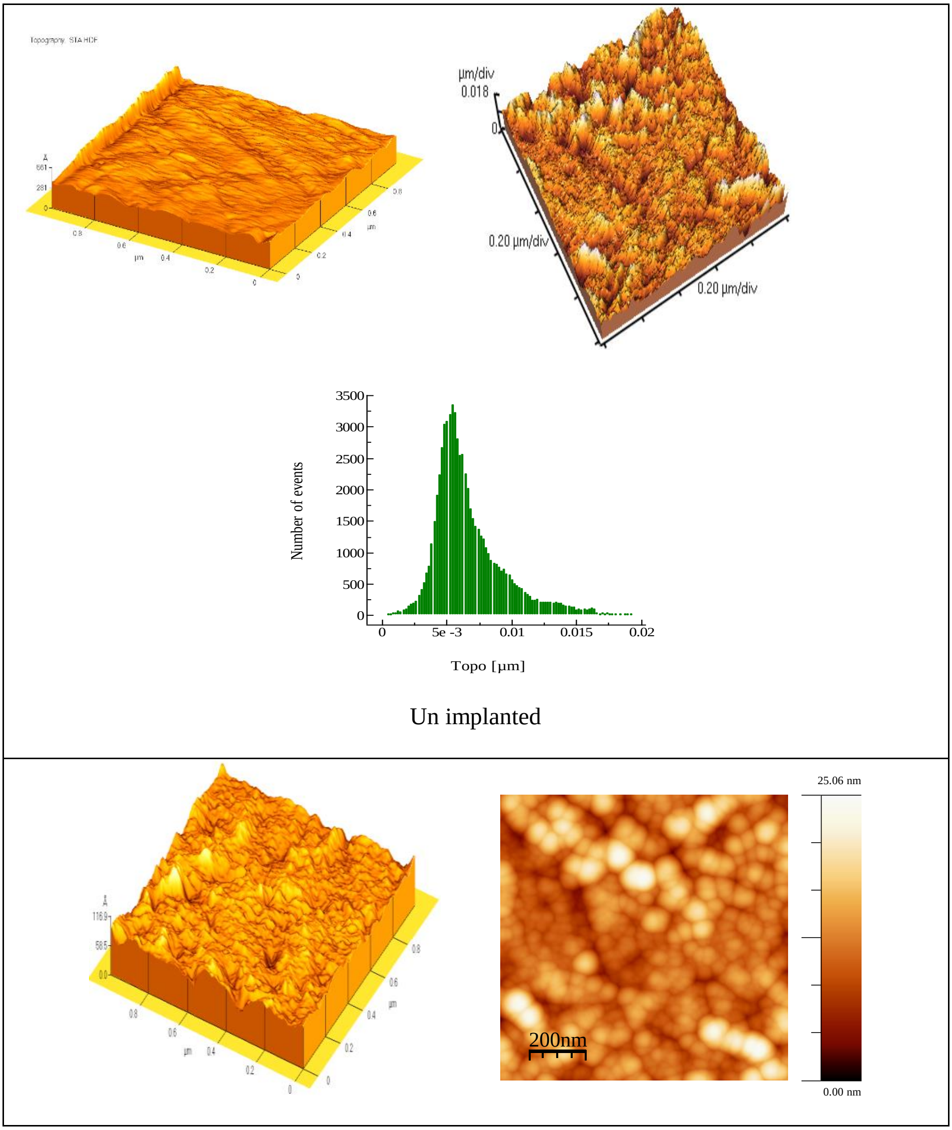
Sample	**Fluxes (ions/cm^2)**	**Time(s)**	Energy(kev)
S1	1×10^{17}	360	30
S2	3×10^{17}	470	30
S3	5×10^{17}	700	30
S4	7×10^{17}	1120	30
S5	10×10^{17}	1600	30

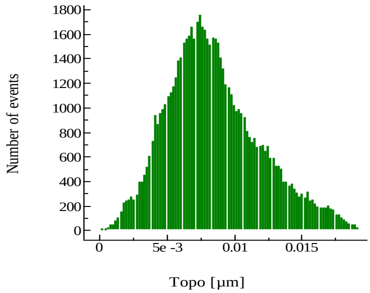
3. Measurements and discussion

The structural properties and composition of the tantalum samples have been investigated with different methods. The implantation-induced modification of surface roughness is studied employing an atomic force microscopy (AFM). SPM Auto Probe CP, Park Scientific Instruments to investigate the morphology and roughness of the surface, performed atomic force microscopy (AFM). AFM was carried out in a non-contact mode and in the scanning area of 1 lm2 with a low stress tip of less than 20 nm radius. In order to study the topography and roughness of the surface, AFM analysis in contact mode and scanning area of 1 lm 2were used.

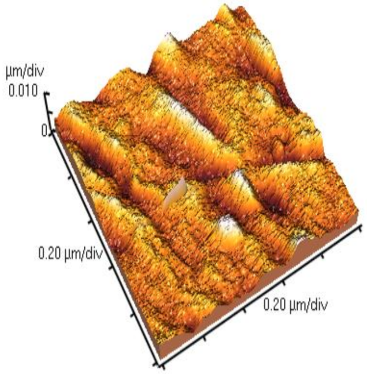
3.1 Surface morphology study by AFM

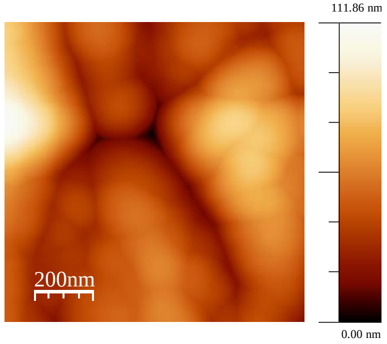
Fig.2, shows 3D AFM surface images of Tantalum based films before and after Nitrogen and Argon ion implantation.

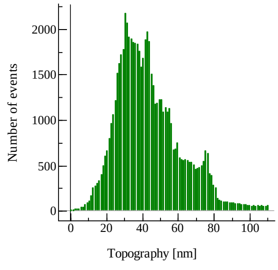

µm/div
0.018
0
0.20 µm/div
0.20 µm/div
3500
3000
2500
2000
1500
1000
500
0
Number of events
0
5e -3
0.01
0.015
0.02
Topo [µm]
Un implanted
25.06 nm
200nm
0.00 nm



Nitrogen ion implanted samples by doses of 1×10^{17}, ion/cm^2







Argon ion implanted samples by doses of 1×10^{17}

Figure 2. 3D images of un implanted sample and Nitrogen and Argon ion implanted samples

The AFM analysis images show the shape and the grain size of a 1μm ×1μm scan area which change with nitrogen ions dose. Table 2 and Table 3, for all samples present the comparison of roughness before and after Argon and Nitrogen ion implantation, respectively.

Table 2. Roughness before and after Argon implantation for all samples.

	Un-implant	S1	S2	S3	S4	S5
Dose	0	1×10^{17}	3×10^{17}	5×10^{17}	7×10^{17}	10×10^{17}
RMS roughness (A˚)	22.3	7.52	41.1	95.3	50.3	7.52
Average roughness (A˚)	15.7	5.64	32.8	69.7	41.3	29.7

Table 3. Roughness before and after Nitrogen implantation for all samples.

	Un-implant	S1	S2	S3	S4	S5
Dose	0	1×10^{17}	3×10^{17}	5×10^{17}	7×10^{17}	10×10^{17}
RMS roughness (A˚)	1401	22.1	18.9	59.9	23.6	4
Average roughness (A˚)	41.9	61.9	50.3	17.1	76.3	10.5

. Fig. 3 shows the samples roughness as a function of ion doses for two different ions; Argon and Nitrogen.

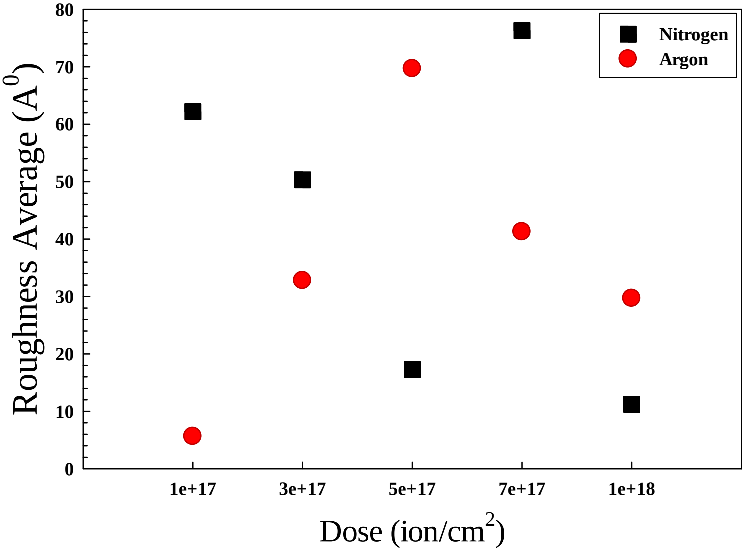


Figure 3. The average roughness of samples as a function of ion doses.

3.2 Transmission Probability and Transport Properties

The value roughness average is one of the parameters which described the surface roughness. Thus, calculation of transport properties have been done to achieve comprehensive information about the type of interfaces. Here, the roughness effect on the transport properties of Tantalum based samples (which they produced by two different ions types implantation) has been studied. Based on the transfer matrix method and nearly free electron mass, the transport properties of un-implanted and implanted samples have been investigated. The detailed descriptions can be fined in Refs [17, 19].
Fig.۳ shows the portion of scattering because of rough Tantalum thin films which have been used in the five layers' structure. The first and third interfaces of this structures have been considered rough. The resonant tunneling happens when the energies of the incident electrons equal with the energy of the lowest quasi bound energy level in the wells [19]. This is the origin of peaks and valleys in the transmission probability curves.

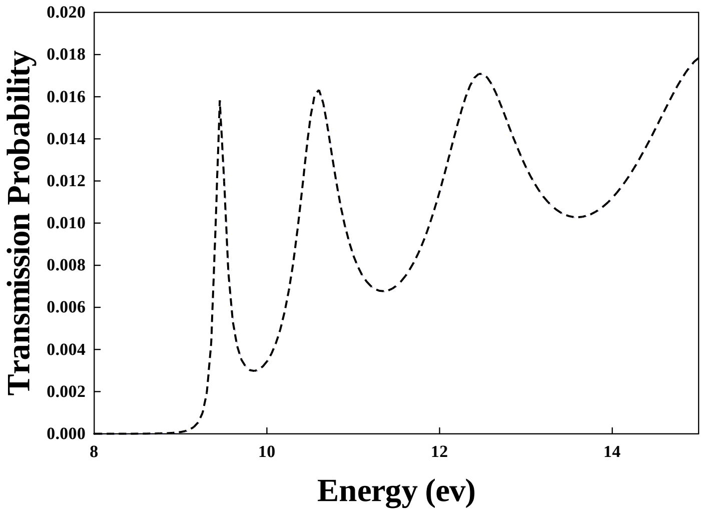


Figure 4. The transmission probability as a function of electron energies for Un-implanted Tantalum thin film.

In the present work, the five layers structures have been considered. Their interfaces are Tantalum based samples which have been implanted by Argon and Nitrogen ions with different doses. Therefore, it is interested to study the effect of ions type on the transport properties of these structures. In the Fig. 5, the portion of scattered of transmission probability has been shown to compare the effect of ion types on the transmission probability. Moreover, the electron scattering process can create the additive dip and peak resonance energies and the resonant peaks in transmission probability do not reach to unit.

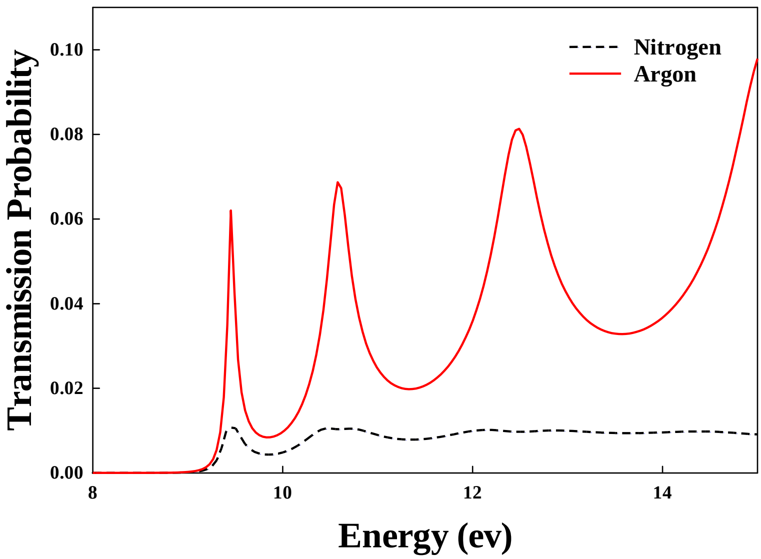


Figure 5. The transmission probability as a function of incident electron energies for structures with Nitrogen ion implanted (dotted curve) interfaces, and Argon ones.

As it can be seen, the scattering portion of transmission probability of structures with the interfaces that produced by Argon ion implantation is more than the Nitrogen one. In order to investigate the effect of ion type for producing the rough interfaces, the current-voltage (I-V) characteristics have been studied. In Fig. 6, the current density as a function of voltage has been plotted for un-implanted interfaces. With increasing the applied voltage (v), the current value reaches a maximum rate and then at higher values of voltage, the current density drops in a region of negative differential resistance (NDR) [17]. The results present that the current-voltage characteristics show negative differential resistance

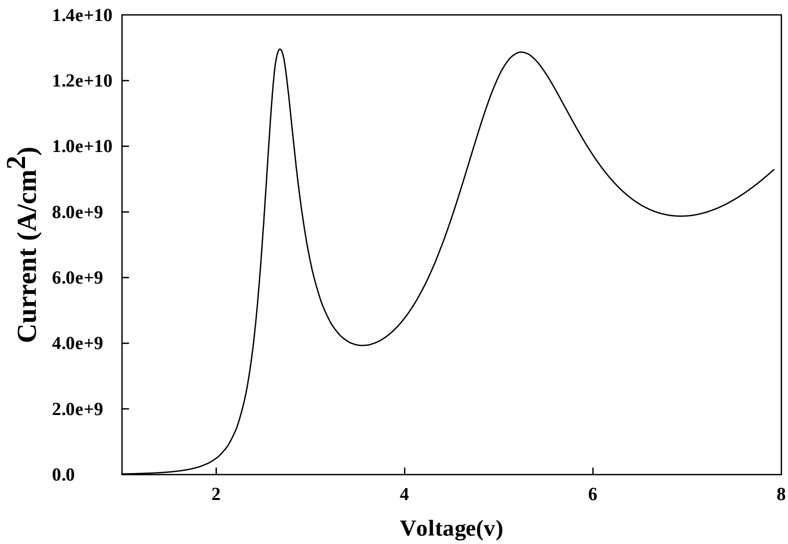


Fig. 6. The current density as a function of the bias voltage for un-implanted case.

In Fig. 7, the effect of interface roughness (which have been produced by Argon and Nitrogen) has been shown on the current density. These results can be explained with the results of Fig. 3.

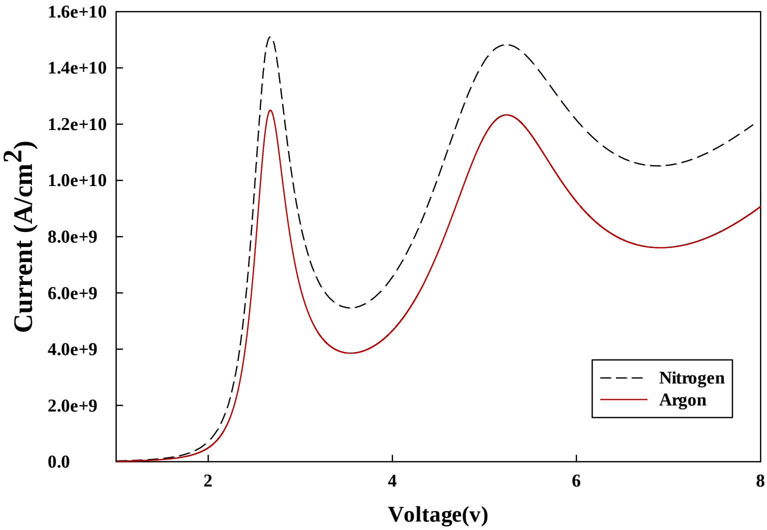


Fig. 7. The current density as a function of the bias voltage for two cases of Argon and Nitrogen ion implanted interfaces.

The scattering portion of probability in the case of Argon ion implantation is more than Nitrogen one. The current density is also less than the Nitrogen case. Moreover, in two cases, as a result of scattering process, the resonant tunneling peak current decreases. Also, the valley current increases and the peak to valley ratio (PVR) reduces. Fig. 8, shows the current density as a function of the bias voltage to describe the effect of two rough interfaces which have been produced by two doses of Nitrogen ions.

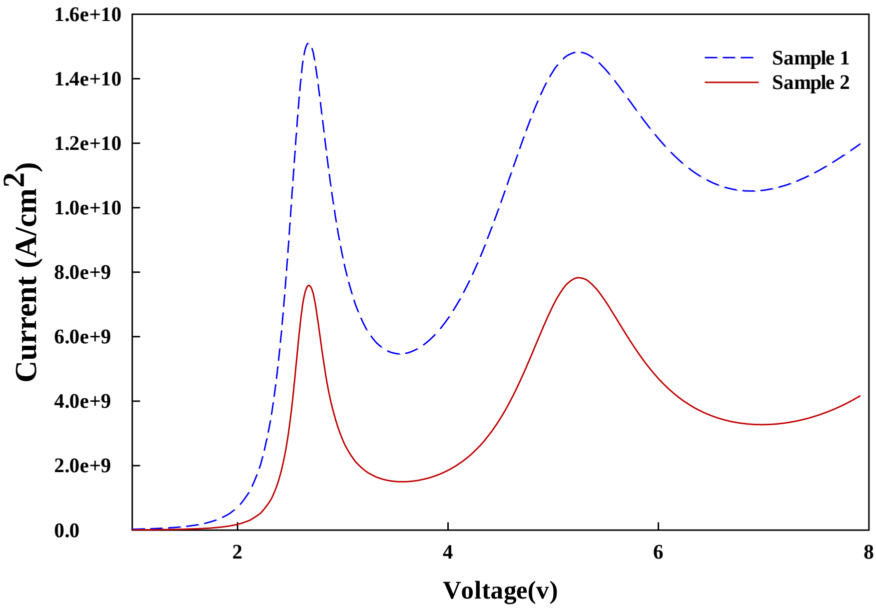


Fig. 8. The current density as a function of the bias voltage for two cases; 1×10^{17} (dotted curve), and 3×10^{17}, ion/cm^2 Nitrogen doses.

Based on the results, the current density has been reduced by increasing the ion doses. This is because of that the interfaces become rougher. These results can be used in the electronic devices fabrication [15].

4. Conclusion

In this study, the effect of ion types (Argon and Nitrogen) implantation has been investigated on the tunneling structures transport properties. The AFM analysis has been used to describe the roughness of produced samples, and the values of average roughness have been calculated. The transmission probability decreases because of the rough interfaces. The rough interfaces have been grown by ion implantation process. As a consequence of scattering process, the resonant tunneling peak current decreases and also, the peak to valley ratio (PVR) reduces. The samples which have prepared by Argon ion implantation were rougher than Nitrogen ones. Also, with increasing the Nitrogen ion doses, the current density has been decreased as a function of voltage.

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