Synthesis of Tantalum-Oxide Thin Film with Reactive DC-Magnetron Sputtering in Electron-Cyclotron-Resonance (ECR) excited $Ar+O_2$ Plasma

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In oxygen plasmas excited with the electron cyclotron resonance (ECR), oriented thin films of Ta_2O_5 have been successfully deposited on quartz substrates above T_{sub} = 450°C with the reactive DC magnetron sputtering. The effects of experimental conditions -- the partial pressure of oxygen and the substrate temperature -- have been examined on the deposition rate and the X-ray diffraction characteristics of deposited films.

1. Introduction

The plasma and particle beam assisted processes have become wide spread as basic techniques for the doping of the compound semiconductors$^{1)}$ and reactive sputter coating with metallic oxides$^{2)}$, most of them have extremely high melting points. Ta_2O_5, tantalum oxide has recently been applied in the semiconductor industry as a dielectric material for integrated capacitors and for the surface protection. These applications are essentially based on its high chemical stability and the insulation resistance. The piezoelectric phenomena in the oriented films have attracted attentions and the applications have been investigated as a medium for the surface acoustic wave (SAW) devices2) In the present work, reactive sputter coating of tantalum oxide was realized in oxygen atoms excited with the electron cyclotron resonance plasma and effect of the enhanced sticking probability has been examined. The crystalline property of deposited film was studied with the X-ray diffraction and compared with the result with the RF magnetron sputter coating2).

2. Experimental setup

In the present experiment, we expected the enhancement of the deposition rate with the ECR plasma source. The starting point for the present discussion was the construction of a microwave discharge in a tapered wave guide, illustrated in Fig. 1. A ceramic chamber was installed inside and filled with oxygen + Ar mixture at about 6 m Torr. Also shown in Fig. 1 is the spatial variation of the strength of the axial magnetic field. The field coil generated a single resonance region at z =35 to 45 mm from the window. The plasma was excited with a microwave source (2450 MHz, 600 W, 50 % duty ratio) and expanded towards the processing chamber along the divergent magnetic field. A magnetic multicusp was installed around the central part of the plasma source, to stabilize the dissipative drift instability.

Metallic atoms were supplied from a compact circular magnetron, illustrated in Fig. 2. Nd - Fe magnets (B ≈ 0.4 T) imposed a local magnetic field in front of the disc target, 99.99 % Ta. The spatial distribution of the strength of the magnetic field, illustrated in Fig. 2 shows that a closed region of the magnetic line of force was formed between the center and surrounding magnetic poles. The circular magnetron forms the cathode of a DC diode discharge. Coaxial anode ring was placed close to the cathode and a DC potential of up to 1 kV was applied between the electrodes.

3. Experimental result

In Fig. 3 (a) one can find decrease in the deposition rate in oxygen-rich conditions compared with the metallic mode in Ar-rich conditions. Better (200) orientation was obtained at the partial pressure of the oxygen 67 - 75 %. In experiments indicated with Si, Ta_2O_5 was deposited on a layer of silicon oxide on (100) Si substrates for the comparison with the results obtained with quartz substrates.

The crystalline properties of the Ta_2O_5 varied depending on the substrate temperature T_{sub}, illustrated in Fig. 3(b): The symbols × indicate the amorphous, △ poly-crystalline, ○ and □ (200) oriented film At T_{sub} lower than 350°C, transparent film was deposited and from it's XRD pattern the film was amorphous. Poly-crystalline films were obtained at 350°C and above when the deposition rate was relatively low rate. (200) oriented thin film was deposited at T_{sub} = 400 - 450 °C. The deposited film was apparently opaque due to the scattering at the crystalline boundary.

In Fig. 3(b), □ indicates the maximum deposition rate obtained with the adjustment of the incident angle of the ECR plasma flux onto the magnetron target. The symbol +indicates the maximum value of the deposition rate with DC discharges. In the present plasma source, the enhancement of the deposition rate was about 20 %.

In the present results, we can not point out outstanding increases in the deposition rate using the ECR excited plasma. In the oxygen rich conditions, however, once the cathode surface is coated with metallic oxide, electrical resistance was introduced in series to the discharge circuit resulting in significant decreases in the deposition rate and frequent excitations of the DC discharge. Thus, we can find the advantage of the present system. The microwave discharge can avoid the risk of the arcing at the beginning and at the restarts of the DC discharge. The discharge current can be maintained at relatively high level even in oxygen-rich conditions.

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References

1) Takashi Matsumoto, Tsuneo Inaba, Yasuo Yoda, Katsumi Egashira, Takamasa Kato, and Tetsuya Akitsu, Journal of Crystal Growth138 (1994) 403-407.

2) Yasuhiko Nakagawa, Yasuo Gomi, and Takashi Okada, J. A. P. 61 (11) (1987) 5012-5017.

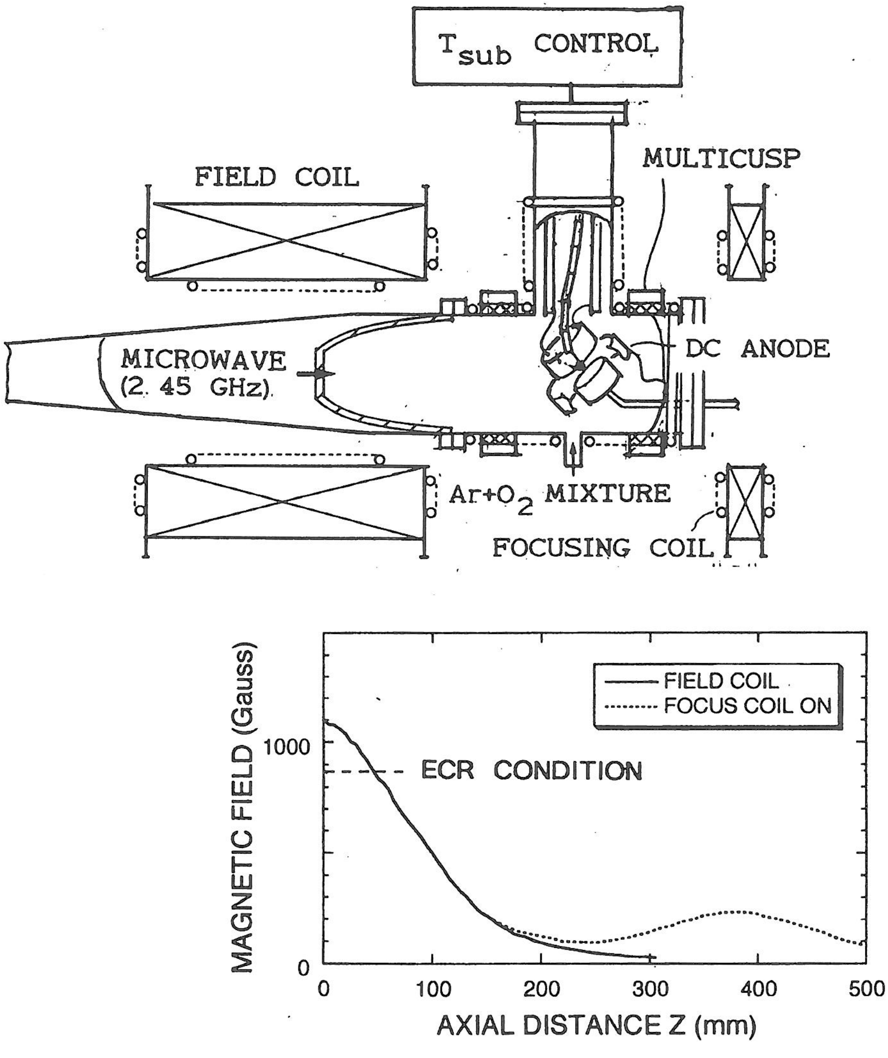

Figure 1 The electron cyclotron resonance plasma source and the strength of the stationary magnetic field as the function of the axial distance. T$_{sub}$ CONTROL indicates a PID control system for the stabilization of the substrate temperature.

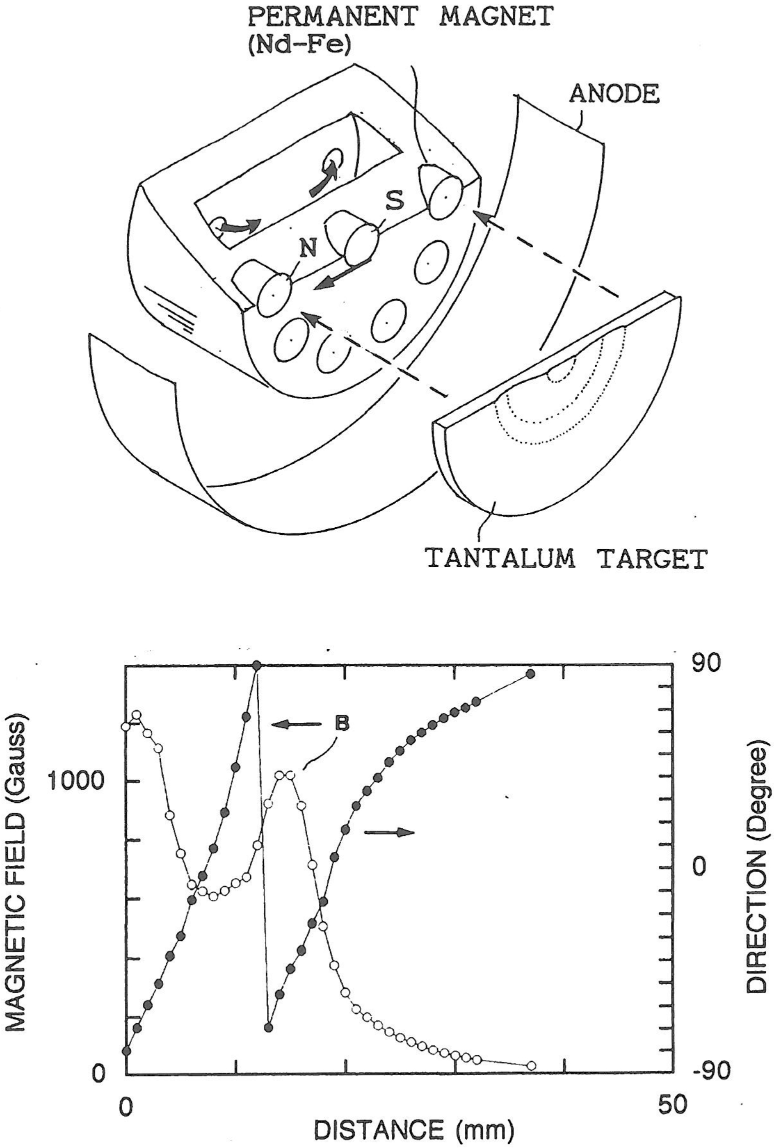

Figure 2. A compact circular magnetron target (cathode) and a coaxial anode ring. The spatial variation of the magnetic field was measured along the path indicated with the straight arrow.

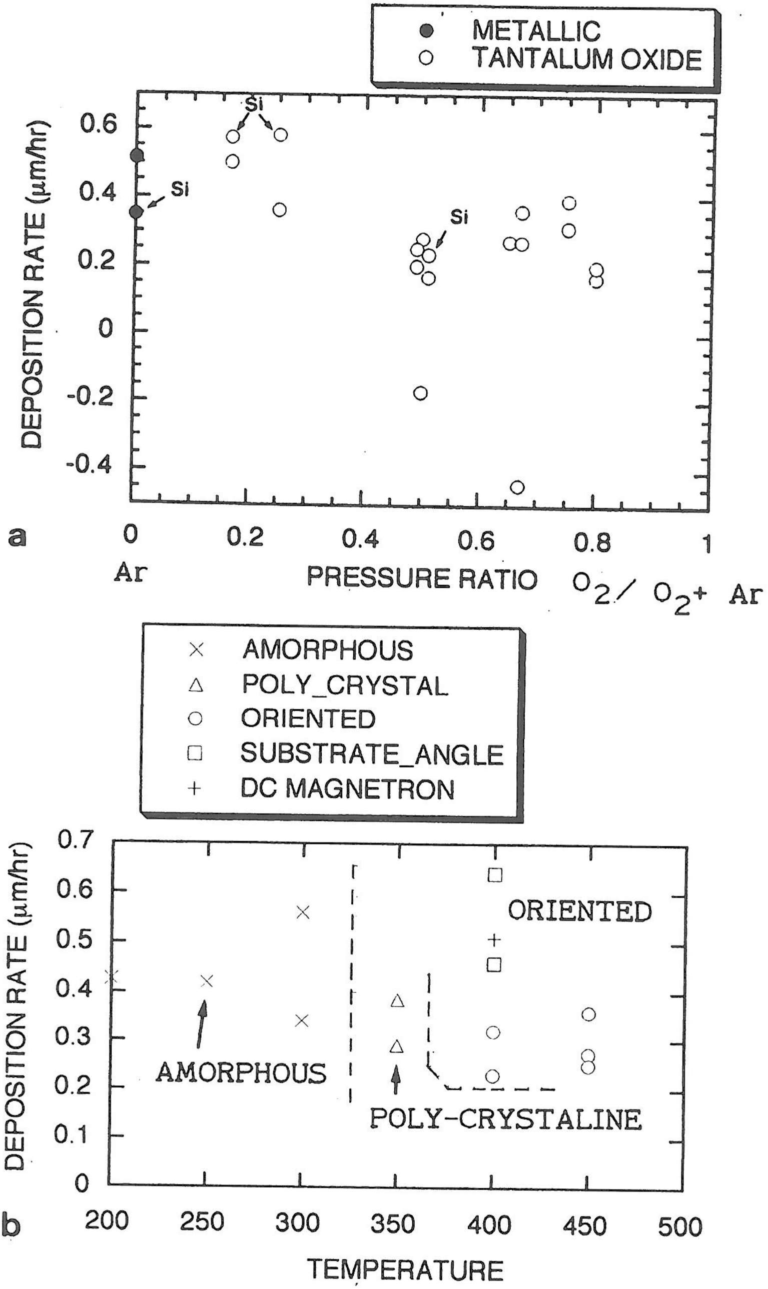

Figure 3 The experimental comparison of the deposition rate and the crystalline property of the deposited films