Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo, 1985, pp. 275-278

Leakage-Current Reduction in Thin Ta_2O_5 Films Using High Purity Ta Target

Chisato Hashimoto and Hideo Oikawa
NTT Atsugi Electrical Communication Laboratories, Atsugi-shi, Japan
Nakahachiro Honma
NTT Musashino Electrical Communication Laboratories, Musashino-shi, Japan

A high purity Ta sputtering target has been developed, and a mobile-charge-free sputtering system has been constructed employing this target in an RF magnetron sputtering apparatus with an ultra-clean sputtering chamber. Leakage current in Ta_2O_5 film deposited by reactive sputtering with this clean sputtering system is drastically reduced, compared with that using a conventional target. It is low enough for use as a storage capacitor in the forthcoming ultra-high-density MOS d-RAM.

I. INTRODUCTION

The highest density MOS d-RAM reported is a 1-Mbit one[1]. To integrate greater numbers of bits on a single chip, further reduction of memory cell area, and particularly of storage capacitor area, is necessary. One effective approach is adopting a trench capacitor to obtain a large effective capacitor area[2]. Another competitive approach is the use of high-dielectric-constant Ta_2O_5 film as capacitor insulator[3], instead of SiO_2 film.

However, Ta_2O_5 film is considered to be leaky, especially after annealing[4],[5]. Certain methods have been attempted for overcoming this drawback: using anodized Ta_2O_5[3] and forming double layered film of Ta_2O_5 and SiO_2[6].

There has been, however, little discussion on Ta_2O_5 film purity, though purification of material is essential before it can be used for Si LSI fabrication. Therefore, we have initiated the investigation of Ta_2O_5 film purification. Sputtering was chosen as the Ta_2O_5 forming method due to its process simplicity.

First, we examined the relation between Ta_2O_5 film purity and leakage current, and proved that leakage current can be drastically reduced using a high purity Ta sputtering target. This report describes the development of a high purity Ta target, the deposition method of a high purity Ta_2O_5 film using this target, and the effect of this purification on Ta_2O_5-film leakage current.

II. Ta_2O_5 FILM PURIFICATION

A. High purity Ta target development

A high purity Ta target was fabricated with recourse to the method established for Mo[7]: Commercially available 3N(99.9%-pure) raw Ta powder was sintered, and the sintered compact was purified three times by electron-beam melting in a high vacuum. The ingot was extruded and machined into a disk-shaped target 5 mm thick and 200 mm in diameter.

Table I contrasts impurity concentrations of this high purity target with those of a conventional 3N Ta target. In the conventional target, impurity concentrations range from one to several dozen ppm. For high purity target, concentrations of alkaline metals, heavy metals, semiconductor, and radioactive elements were reduced to less than 0.05ppm, less than 0.1ppm, 0.05ppm, and less than 0.001ppm, respectively. Therefore, these impurity concentrations have been reduced by 2 or 3 orders in magnitude. Target purity was estimated to be above 4N. Details of the analysis will be reported elsewhere[8].

TABLE I. IMPURITIES IN Ta SPUTTERING TARGETS (wt.ppm)

Impurities		High Purity Target	Conventional Target
Alkaline Metals	Na	<0.05	< 1
	K	<0.05	< 1
Heavy Metals	Fe	<0.1	25
	Ni	0.05	<10
	Cr	<0.1	<30
Semiconductor Element	Si	0.05	15
Radioactive Element	U	<0.001	
Purity		>4N	3N

Main Measurement Methods
Alkaline Metals: Flameless Atomic Absorption
Heavy Metals: Spark Source Mass Spectrometry
Semiconductor Element: Spark Source Mass Spectrometry
Radioactive Element: Fluorescence Spectrophotometry

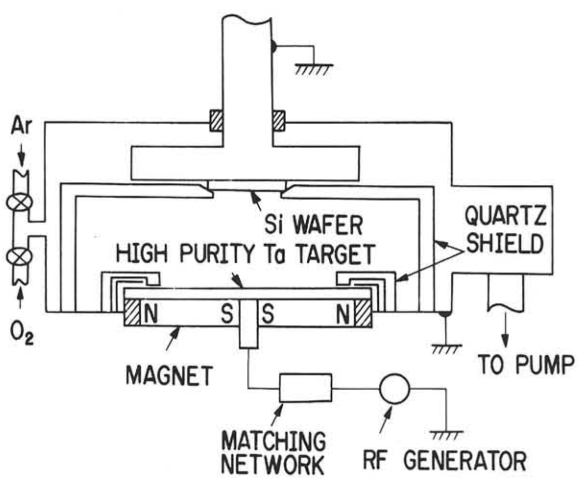

Fig.1 Schematic diagram of clean sputtering system

B. Clean sputtering system construction

The high purity Ta target was installed in an RF magnetron sputtering apparatus where all parts in the sputtering chamber exposed to Ar plasma were covered by high purity(above 99.999%) quartz shields. A schematic diagram of the apparatus is shown in Fig.1. The target surface was sputtered with Ar ions until target surface contamination was entirely removed. Subsequently, pure Ta was deposited onto the surface of the quartz shields to prevent Si incorporation into Ta_2O_5 during Ta_2O_5 deposition.

Mobile charge density in the deposited film incorporated during sputtering was examined by fabricating MOS capacitors with a Ta/SiO_2/p-Si structure. A circular shaped Ta electrode was deposited onto thermally grown 200-Å-thick SiO_2 through a quartz plate mask to avoid contamination incurred during the lithographic process. Some samples were annealed for 30 min at 1000°C in N_2. Then, TVS(Triangular Voltage Sweep) measurements were carried out.

Comparisons of mobile charge densities in Ta gate MOS capacitors fabricated with high purity and conventional 3N Ta targets are shown in Table II. When capacitors were not annealed, mobile charges were less than the detectable limit, regardless of target purity used. On the other hand, after 1000 °C annealing, distinct differences appeared: mobile charges of 1×10^{13} cm^{-2} were detected for the conventional target, while none were detected for the high purity target. This indicates use of a high purity target drastically reduces mobile charges in the deposited film.

High purity Ta_2O_5 films were grown by reactive sputtering in an Ar-O_2 mixture using this clean sputtering system. Total gas pressure was maintained at 5×10^{-3} Torr throughout the experiment.

TABLE II. MOBILE CHARGE DENSITIES IN Ta GATE MOS CAPACITORS

	High Purity Target	Conventional Target
No Anneal	Undetected	Undetected
N_2 1000°C Anneal	Undetected	1×10^{13} cm^{-2}

(Detectable limit 3×10^{9} cm^{-2})

III. LEAKAGE CURRENT REDUCTION IN THIN Ta_2O_5 FILM

MOS capacitors with Al/Ta_2O_5/p-Si structure were fabricated to measure leakage current. The Ta_2O_5 film was deposited on 4.5-Ωcm (100) p-Si substrates using the high purity or conventional Ta targets. Al electrodes with an area of 6.25×10^{-4} cm^2 were formed by evaporation and photolithography. Some samples were annealed for 1 hr at 500℃ in O_2 before Al deposition.

The Schottky plot of current flowing through the Ta_2O_5 film in the MOS capacitors is shown in Fig.1. Here, sample wafers were set in an optically and electrically shielded box, and current measurements were carried out 3 min after each bias-voltage setting to ensure a steady state. All measurements were taken with negative voltage to the Al electrode.

Leakage current was drastically reduced using the high purity target, as clearly shown in Fig.2. Surprisingly, film leakage-current density as thin as 140 Å, deposited using the high purity Ta target, even after annealing at 500℃ in O_2, was more than two orders lower than that of the as-deposited 350-Å-thick film using the conventional target. Of course, leakage current density of the thicker film (640 Å) was about one-order lower than that of the 140-Å-thick film after annealing. Leakage current of as-deposited 640-Å-thick film was still more than one-order lower than that of annealed film with the same thickness.

It is clear from the figure that curves have almost the same slope and that the current transport in the films can be well explained by the Pool-Frenkel mechanism, even purified films. Therefore, further leakage-current reduction can be expected through further purification of film. This results in the trap-density reduction in the film.

On the other hand, the dielectric constant of Ta_2O_5 film deposited on Si decreases with decrement of film thickness due to the very thin SiO_2 layer at the interface between Si and Ta_2O_5[9]. For example, the relative dielectric

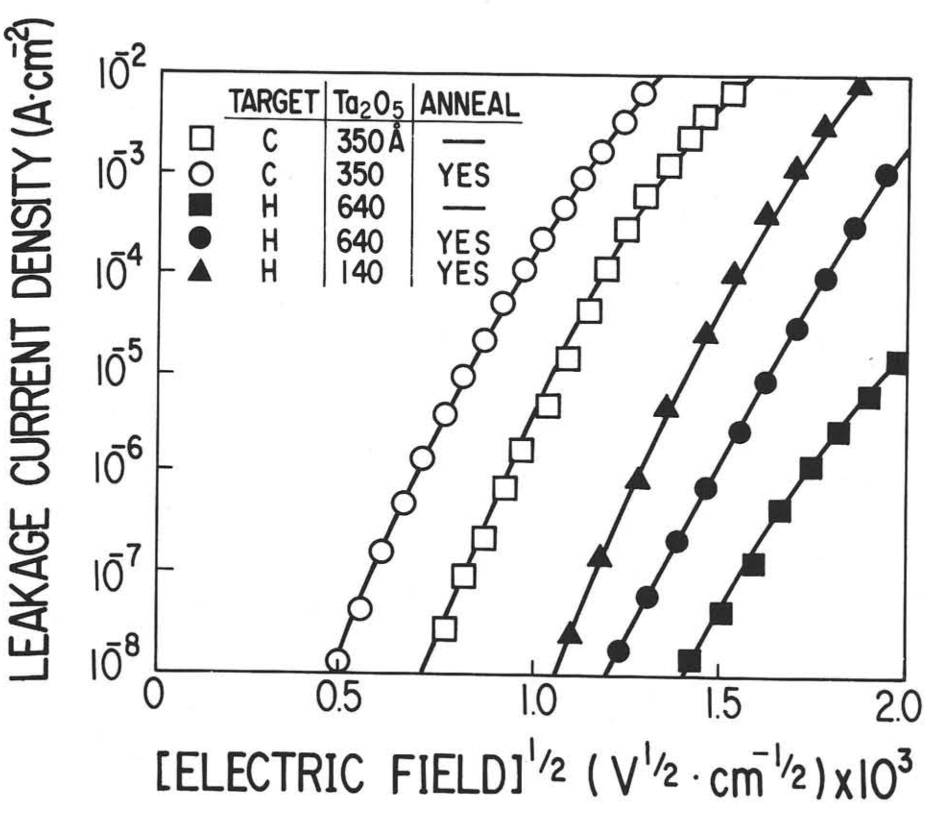

Fig.2 Leakage current of Al/Ta_2O_5/p-Si MOS capacitors. Ta_2O_5 film was deposited using a conventional(C) and high purity(H) Ta target. Some film was annealed at 500℃ for 1 hr in O_2. Al electrodes were negatively biased.

constant of the 140-Å-thick film is 11. Our investigation shows, however, this decrement of dielectric constant is not essential, i.e., Mo electrode, instead of Si one, can prevent this with little leakage-current increment[10]. Therefore, assuming the relative dielectric constant of Ta_2O_5 is 25 and the voltage applied to a capacitor is 2V, value 32fC/μm^2 is obtained for the storage charge using 140-Å-thick Ta_2O_5 film as the capacitor insulator. In this case, leakage current density is only below $2x10^{-15}$ A/μm^2. It is concluded that the remarkable leakage current reduction obtained in the present study raises Ta_2O_5 film to a level applicable as a storage capacitor insulator in the forthcoming ultra-high-density d-RAM.

IV. CONCLUSION

A high purity Ta target has been developed. A mobile-charge-free sputtering system has been constructed by installing this target in an RF magnetron sputtering chamber with high purity quartz shields. Leakage current in the Ta_2O_5 film deposited by reactive sputtering with this sputtering system was found to be exceedingly low. This means Ta_2O_5 can be used for a storage capacitor insulator in an ultra-high-density d-RAM, without trench capacitor technology.

ACKNOWLEDGEMENT

The authors would like to thank Drs. Mamoru Kondo, Eisuke Arai and Seiji Hattori for their advice and encouragement. They also thanks Drs. Yasushi Nakamura and Osamu Kanou of Nippon Mining Co.,LTD. for target preparation and impurity analysis.

REFERENCES

[1]J. Yamada, T. Mano, J. Inoue, S. Nakajima, and T. Matsuda:ISSCC Dig. Tech. Papers, pp.104-105, 1984.

[2]K. Minegishi, S. Nakajima, K. Miura, K. Harada, and T. Shibata:IEDM Tech. Dig., pp.319-322, 1983.

[3]K. Ohta, K. Yamada, K. Shimazu, and Y. Tarui:IEEE Trans. Electron. Devices, vol.ED-29, pp.368-376, 1982.

[4]P. L. Young, F. P. Fehlner, and A. J. Whitman:J. Vac. Sci. Technol., vol.14, pp.174-176, 1977.

[5]S. Kimura, Y. Nishioka, A. Shintani, and K. Mukai:J. Electrochem. Soc., vol.130, pp.2414-2418, 1983.

[6]T. Kato, T. Ito, M. Taguchi, T. Nakamura, and H. Ishikawa:Proc. Symp. VLSI Tech., pp.86-87, 1983.

[7]T. Amazawa, H. Oikawa, N. Shiono, and N. Honma:Extended Abstracts of 16th Conf. Solid State Devices and Materials, Kobe, pp.269-272, 1984.

[8]N. Honma:to be presented in Jpn Soc. for Analyt. Chem. 34th Annual Conference, 1985(in Japanese).

[9]Y. Nishioka, S. Kimura and K. Mukai:Extended Abstracts of 165th Electrochem. Soc. Meeting, Cincinnati, pp.190-191, 1984.

[10]C. Hashimoto and H. Oikawa:to be presented in Jpn Soc. of Appl. Phys. 46th Fall Meeting, Kyoto, 1985(in Japanese).