Extended Abstracts of the 21st Conference on Solid State Devices and Materials, Tokyo, 1989, pp. 21-24

Reduction of Internal Stress by Compositional Gradient Layer Inserted between $TiSi_2$ and Si

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This paper is concerned with the experimental results to reduce the internal stress due to heat treatment of $TiSi_2$/Si strcture. In order to reduce the stress a compositional gradient layer is inserted between two layers. A plasma controlled sputtering is newly proposed to deposit a compositional gradient layer. A 0.2 μm thickness of linearly graded transition layer can reduce the internal stress to zero after annealing.

1. INTRODUCTION

Titanium disilicide is an important material for the present generation of silicon based semiconductors[1-2]. It is applied as a diffusion barrier or as contact and inter-connection material. It can be produced by alternating sputter deposition of Si and Ti thin layers and subsequent heat treatment. During deposition of layers on Si wafers, or during the annealing, stress may develop[3-4]. These stresses are mainly induced by difference in the thermal expansion coefficient between the layer and the substrate and phase transformation of deposited material. If the stresses become too large, the integrity of the gate oxide of MOS transistor will be damaged. In order to reduce the stress a compositional garadient layer is inserted between $TiSi_2$ and Si. In this paper, the details of compositional gradient layer deposition by plasma controlled sputtering technique are presented, as well as the results of stress relaxation.

2. PLASMA CONTROLLED SPUTTERING

Figure 1 shows the plasma controlled sputtering[5-6] used in our experiment. In

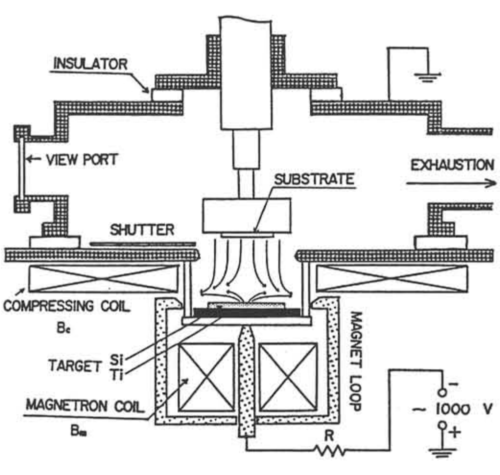

Fig.1 Chamber of plasma controlled sputtering.

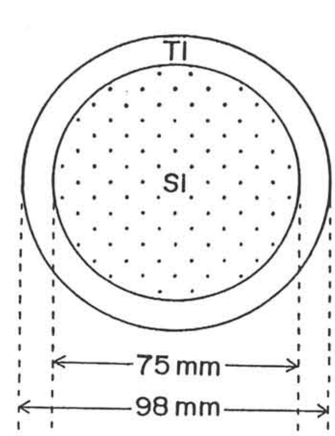

Fig.2 Target configuration of composition control.

order to control the parallel component of the magnetic flux to the target surface, two electric magnets, which are repulsive each other, are set above (Bc) and beneath (Bm) the target. In this configuration, increasing the magnetic field of compressing coil (Bc) and decreasing that of the magnetron coil (Bm) concentrate the plasma to the target center, and vice versa. The plasma is confined the portion of parallel magnetic field to the target surface. Thus, the erosion erea of the target corresponds to the place where the plasma exists and it is greatly affected by these two magnetic field distributions. Therefore, if a refractory metal disk or ring is placed on the Si target, it is possible to control the composition ratio (Si/metal) of sputtered films by changing Bm and/or Bc.

3.EXPERIMENTAL RESULTS

3.1 Control of Composition ratio

A 75 mm diameter Si disk target was put on the 98 mm diameter Ti target as shown in Fig.2. The sputtering condition is shown in Table 1. At first the sputtering species were checked by the Quadrupole Mass Spectroscopy (Q-Mass) by changinghe Bc for constant Bm. The Q-Mass head was placed at the substrate position. Figure 3 shows the relations between Bc and the ion currents of Si and Ti for Bm=630 Gauss. As this figure shows, when Bc is as small as 100 Gauss, a large Ti current is observed because the plasma mainly stays on the Ti. On the other hand when Bc is as large as 232 Gauss, a large Si current signal is observed because plasma is concentrated on the target center. When a shutter is closed, both signals are reduced to zero. Figure 4 shows the magnetic field (Bc) dependences of deposition rate and logarithmic conductivity (log σ) of a sputtered film. The conductivity reflects the composition ratio of Si to Ti[7]. Thus it is possible to control the composition ratio by changing Bc and Bm.

3.2 Deposition of compositional gradient layer

There are two ways to deposit compositional gradient layer. ① One is to control the area ratio of the plasma on the both metal and Si targets. ② The other is to change the time interval to stay the plasma on the metal and Si targets. In this case plasma does not stay across both targets.

Table 1 Sputtering Condition

Ar Gass Pressure	60 mTorr
Gas Flow Rate	10 SCCM
Substrate Temp.	100 ℃
Power	40 W (DC)
Substrate−Target	53 mm

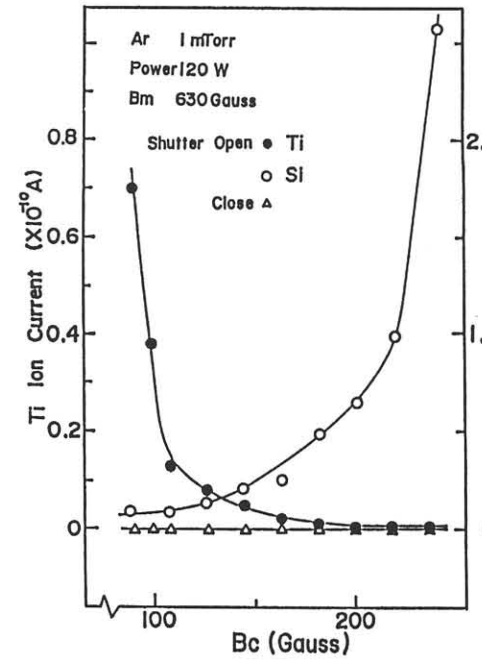

Fig.3 Ti and Si ion currents of Q-Mass.

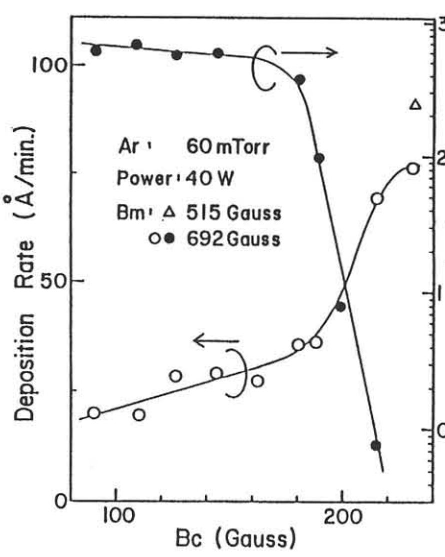

Fig.4 Bc dependences of deposition rate and logarithmic conductivity.

①Control of the plasma area on the targets

As shown in Fig.4 it is possible to change the conductivity gradually by changing Bc and Bm. This is because the area ratio of plasma on the each target changes by changing Bc and Bm. When a compositional gradient film is sputtered, it is necessary to take into account the composition ratio and deposition rate and to determine the amplitude and time interval of the magnetic fields. When these magnetic fields are changed gradually, it is possible to obtain any compositional profile such as linear, hyperbolic, and exponential functions. Figure 5 shows time variations of Bc and Bm to fabricate a linearly graded transition layer.

② Control of the time interval

In this experiment Ta is used insted of Ti of previous experiment. In this case the plasma stays on Si or Ta. Figure 6 shows how to control conductivity for pulsed Bc and Bm magnetic fields. When Bc is as small as B_{c2} and Bm is as large as B_{m1}, only metal film is deposited on the substrate. When Bc is as large as Bc_1 and Bm is as small as B_{m2} in the figure, only Si film is deposited. Therefore, if Bc and Bm were alternately changed as B_{c1} and B_{m2} for T_1s and B_{c2} and B_{m1} for T_2s, the plasma alternately moves to the center and periphery of the target surface. As the sputtering ratio (Si/Ta) of the target is controlled by the duty ratio of Bc and Bm, the composition ratio of Si and Ta is changed. Experiments were performed by the B_{c1}=180 and B_{c2}=72 Gauss for Bm=727 Gauss and the duty ratios, $D=T_1/(T_1+T_2)$ were changed as 0, 30, 40, 50, and 100%. As shown in Fig.7, it is possible to control the composition ratio by the duty ratios.

4. REDUCTION OF INTERNAL STRESS

4.1 Internal stress of films

Induced stress before and after the heat treatment of $TiSi_x$ and Si mono-layer films was determined from the measurement of the radius of curvature of the wafer[8-9]. Films,3200Å in

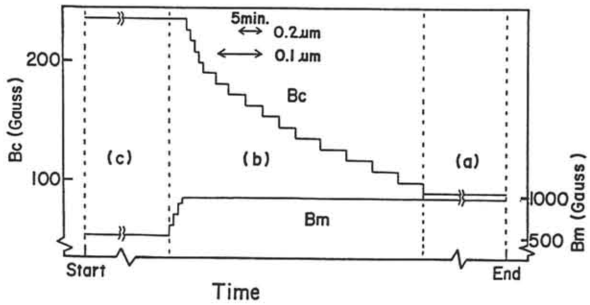

Fig.5 Time variation of Bc and Bm to deposit compositional gradient film by controlling plasma area on the targat.

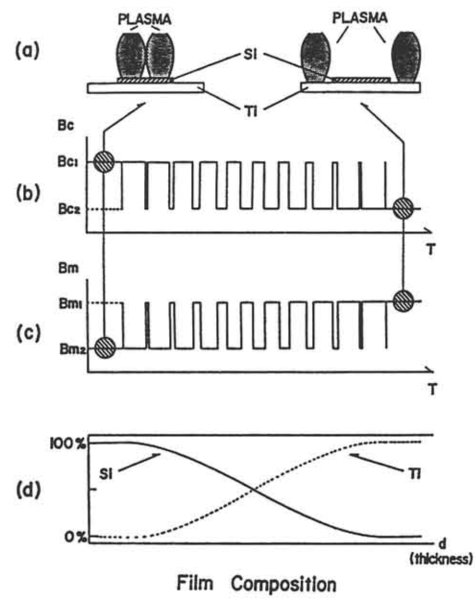

Fig.6 Duty ratio variation of Bc and Bm to deposit compositional gradient film.

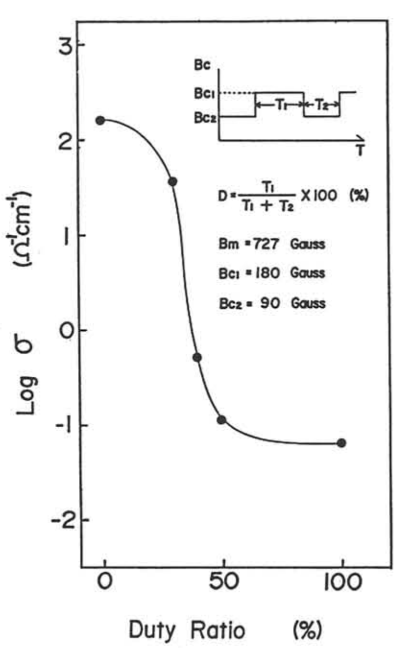

Fig.7 Relation between Log σ of $TaSi_x$ and duty raio.

thickness, were sputtered on fused quartz substrate ($40\times10\times0.3$ mm^3) at 100℃. They were annealed at 900℃ for 20 min. in hydrogen gas ambient. The $TiSi_x$ is deposited so as to become $TiSi_2$ after annealing. The radius of curvature is measured by scanning the whole film surface by a surface roughness detector (Surfcom). The distortion at substrate center in both as-deposited films and $TiSi_2$ increases from 14μm to 115 μm. This large tensile stress is due to the difference in the thermal expansion coefficient between $TiSi_2$ and the substrate. As for a Si film, a compressive stress does not change before and after the annealing. The stresses calculated from experimental results are 0.23×10^9 dynes/cm^2 (tensile) for $TiSi_2$ and 0.24×10^8 dynes/cm^2 (compressive) for Si.

4.2 Relaxation of internal stresses

It is said that a compositional gradient transition layer is effective to reduce the thermally induced internal stress[10]. This technique is applied to reduce the stress existing in the $TiSi_2$/Si structure on thermally oxidised Si wafer. A 3000Å $TiSi_x$ is deposited onto a 5000Å poly Si. A 0.1 and 0.2 µm linearly graded transition layers were deposited between these two layers and annealed at 700℃ for 20 min. Figure 8 shows the stresses before and after annealing for different three samples. When a 0.2 µm transition layer is inserted, the stress reduces to zero after annealing. Thus a moderate thickness and profile of transition layer is very effective to reduce the stresses.

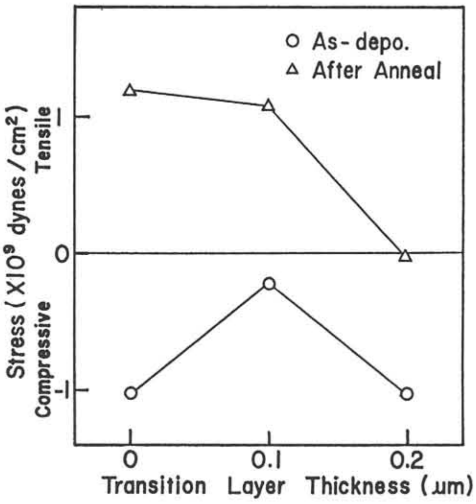

Fig.8 Stresses before and after annaealing for various thickness of transition layers.

5. CONCLUSION

In our plasma controlled sputtering, the magnetic field intensity (Bc and Bm) can control the position of intense plasma on the target surface. Then it is possible to sputter the target element that we want among several composite elements. Two ways to deposit the compositional gradient films have been explained. It is applied to reduce the stress induced in the $TiSi_2$/Si structure and succeeded to reduce it to zero after annealing. Though the $TiSi_2$/Si has been taken as an example, it is applicable to fabricate any structure and to any materials,i.g., metal/ceramics and so on. The authors would like to express their thanks to Dr.K.Wasa of Matusita Electic Industrial Co,Ltd. for useful dissussions and suggestions and to Mr.T.Nishi and Mr.K.Yamamoto of UBE Industries, Ltd. for support to progress our experiments.

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