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Highly Reliable Cu Interconnect using Low Hydrogen Silicon Nitride Film Deposited at Low Temperature for Cu-Diffusion Barrier

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1. Introduction

Low temperature processes for Cu interconnects have been required in the application of new conceptual devices, because the thermal budget is often restricted by the new materials introduced in these kinds of devices. For Magnetoresistive Random Access Memory (MRAM), which is the first candidate of non-volatile memory in the next generation, the Cu interconnect process after Magnetic Tunnel Junction (MTJ) requires a low temperature process of less than 300℃, because the MTJ degrades easily at a higher temperature [1,2] (See Fig. 1). Considering each process in general Cu interconnects, only the deposition temperatures of 400℃ for dielectric films such as p-SiN deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) is fatal, so the temperatures should be reduced to less than 300℃. However, in 300℃-deposition, film properties are considerably degraded, and as a result, the reliabilities of Cu interconnects are also degraded.

In this study, we will show an advanced low-temperature process of p-SiN (LT-SiN) with high film properties as a Cu-diffusion barrier layer, and its impact on the reliabilities on Cu interconnects such as Via-hole electromigration (Via-EM) and line-to-line time-dependent dielectric breakdown (TDDB). Finally, it will be demonstrated that the high reliabilities of Cu interconnects is successfully achieved by the optimization of LT-SiN deposited conditions.

2. Experimental

The silicon nitride film was deposited using a gas mixture of SiH_4, NH_3, and N_2 in a conventional PECVD system. Three samples were prepared using the different deposition conditions. Two kinds of LT-SiN film (LT-SiN-A and LT-SiN-B), deposited at 275℃ with different ratios of SiH_4 gas flow to total gas flow (SFR), were compared with 400℃-SiN that was applied to our standard 130nm node Cu interconnects as the Cu-diffusion barrier layer.

The moisture-blocking ability of the silicon nitride films was evaluated using a pressure cooker test (PCT). The sample structure is shown in Fig. 2. The evaluation method of the PCT is shown in Ref [3]. In this experiment, the time during which the P=O bond area of a spectrum using Fourier transform infrared spectroscopy (FTIR) decreases from 100% to 90% in the PCT is defined as moisture-blocking time (MBT). The leakage current of the silicon nitride was measured using a mercury probe. The hydrogen concentration in the silicon nitride was calculated by measuring the amount of desorbed hydrogen during thermal desorption spectroscopy (TDS) performed at temperatures ranging from 100℃ to 500℃.

Two-level Cu interconnects with 130nm node dimensions (Line/Space = 200/200nm) were fabricated by low temperature processes. Silicon oxide film deposited at 290℃ was applied for the inter-layer dielectrics. Temperatures of other processes were also below 300℃. Distribution of via-hole resistance was evaluated using a 6.5M vias/chain pattern. Via-EM and line-to-line TDDB were investigated under temperature stresses of 300℃ and 250℃, respectively.

3. Results and Discussion

1) Film Characterization of Low Temperature Silicon Nitride

The fundamental film properties of LT-SiN are listed in Table I, with those of the 400℃-SiN as a reference. The SFR during the deposition of LT-SiN-A was 2.3%, the lowest among the samples. The low SFR was realized due to the highly diluted nitrogen gas flow (HDNF). A low temperature deposition provides high non-equilibrium reactions, resulting in high-structural defects in the film [4]. Despite a low deposition temperature, the film properties of LT-SiN-A, such as stress, dielectric constant, density and elastic modulus were comparable to those of 400℃-SiN. On the other hand, the film properties of LT-SiN-B were inferior to those of 400℃-SiN and LT-SiN-A. From these results, the film properties of the LT-SiN deposited at a low SFR below 2.3% achieved by the HDNF are as reliable as those of 400℃-SiN. Figure 3 shows a comparison of the moisture-blocking abilities of the three films. The MBTs of 400℃-SiN, LT-SiN-A and LT-SiN-B were 750 hours, 500 hours and 9.5 hours, respectively. The moisture-blocking ability of LT-SiN-A is comparable to that of 400℃-SiN. It was reported that LT-SiN film has a high hydrogen concentration [5]. The hydrogen concentrations of the three films calculated by measuring the amount of desorbed hydrogen during TDS are shown in Fig. 4. The hydrogen concentration of LT-SiN-A was lower than that of the LT-SiN-B. We speculate that many N ions or radicals in the plasma of the HDNF condition scavenge the excess hydrogen during the silicon nitride deposition, leading to a low hydrogen concentration in the film. From these results, the low hydrogen concentration of LT-SiN significantly improves the moisture-blocking ability of LT-SiN.

The leakage currents of the three films measured using a mercury probe are shown in Fig. 5. LT-SiN-A exhibited the lowest leakage current among the three films. The Si-H bond densities measured using FTIR are shown in Fig. 6. The Si-H bond density of LT-SiN-A was lower than that of the others. There was a good relationship between the density of the Si-H bonds and the leakage current of the film. This indicates that the lower density of Si-H bonds in LT-SiN plays an important role in the reduction of the leakage current of the film. Although 400℃-SiN contained more Si-H bonds than LT-SiN-A (Fig. 6), the hydrogen concentration of 400℃-SiN was lower (Fig. 4). It can be considered that the higher deposition temperature of 400℃-SiN enables greater suppression of the Si-H bond desorption when TDS is performed at temperatures less than 500℃, compared to that of LT-SiN-A.

2) Electrical properties and reliabilities

Via resistance distributions are shown in Fig. 7. No yield degradation was observed for any of the samples. Figure 8 shows the Via-EM characteristics. The Via-EM lifetime of LT-SiN-A was as reliable as that of 400℃-SiN and was superior to that of LT-SiN-B. The line-to-line TDDB characteristics are shown in Fig. 9. The line-to-line TDDB lifetime of LT-SiN-A was superior to that of the others. We speculate that the lower leakage current of LT-SiN-A improves the line-to-line TDDB lifetime. From these results, the LT-SiN-A achieves highly reliable electrical characteristics in Cu interconnects with 130nm dimensions.

In the MRAM processes, an annealing treatment for several hours under magnetic fields is performed as the final process. The lifetimes of the Via-EM and line-to-line TDDB were compared with and without an anneal at 275℃ for 9 hours in the case of the LT-SiN-A sample. There were no significant differences in Via-EM lifetime and line-to-line TDDB lifetime of the LT-SiN-A sample whether the anneal was performed or not, as shown in Fig. 8 and 9, respectively. These results indicate that the LT-SiN-A realizes robust Cu interconnects even when applied to MRAM devices.

4. Conclusion

We successfully obtained the high reliabilities of Cu interconnects using low temperature processes less than 300℃ for MRAM. For these processes, the key technology is LT-SiN deposition with a highly diluted nitrogen gas flow (HDNF) condition, and it is concluded that the N ions or radicals in the plasma scavenge the excess hydrogen, and as a result, low hydrogen SiN film can be obtained at an extremely-low temperature of 275℃.

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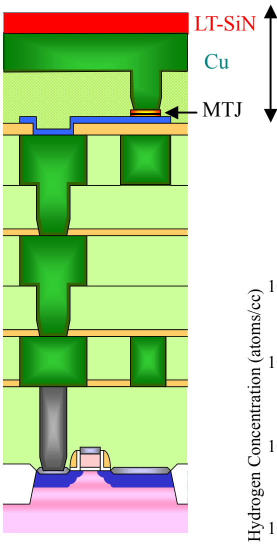

Fig. 1 Cross section of MRAM.

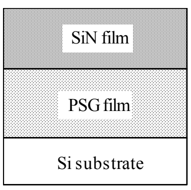

Fig. 2 Film stack of samples for evaluation of moisture-blocking ability.

Table I. Fundamental film properties and deposition conditions of the three samples.

Sample	LT-SiN-A	LT-SiN-B	400℃-SiN
SiH_4 flow ratio (SFR) (%)	2.3	5.2	8.7
Stress (MPa)	-152	245	-180
Dielectric constant	6.5	6.0	6.4
Density (g/cm^3)	2.54	2.29	2.40
Elastic modulus (GPa)	200	158	188
Moisture-blocking time (hours)	500	9.5	750

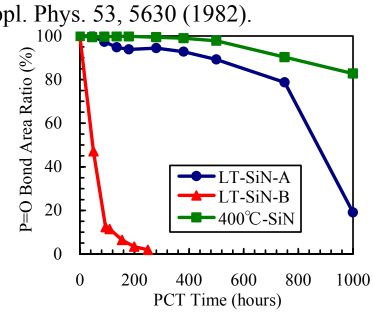

Fig. 3 Moisture-blocking abilities of silicon nitride by a pressure cooker test.

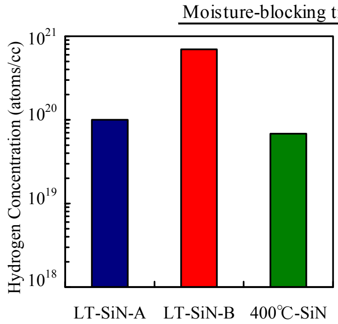

Fig. 4 Hydrogen Concentrations calculated by measuring the amount of desorbed hydrogen during TDS at temperatures ranging from 100℃ to 500℃.

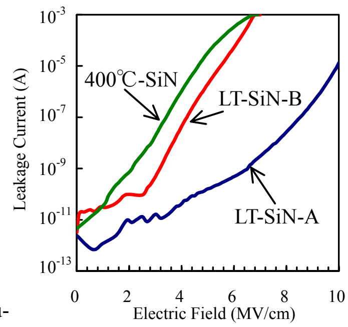

Fig. 5 Leakage currents measured using a mercury probe.

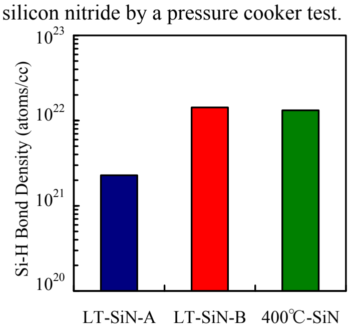

Fig. 6 Si-H bond densities measured using FTIR.

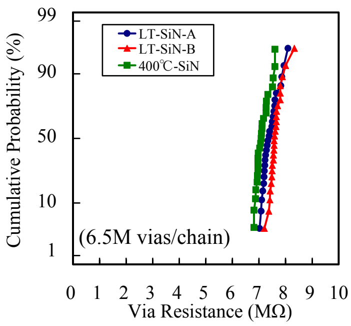

Fig. 7 Distributions of via resistance.

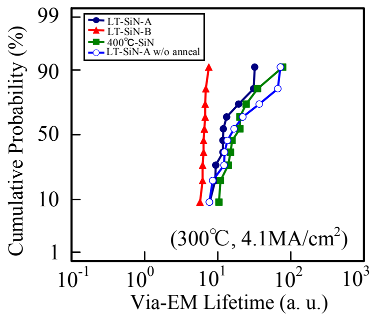

Fig. 8 Cumulative probability distributions for Via-EM lifetime.

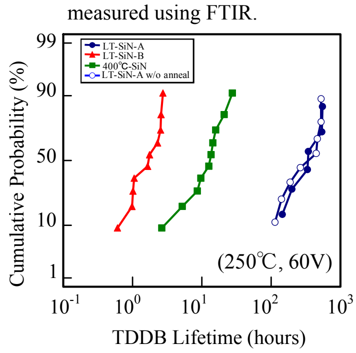

Fig. 9 Cumulative probability distributions for line-to-line TDDB lifetime.