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TaN underlayers for spin valves deposited directly on top of Si substrates

Jiwon Kim, Soonchul Jo*

School of Electronic Engineering, Soongsil University, 511, Sangdo-Dong, Dongjak-Ku, Seoul 156-743, Korea, Republic of Korea

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Abstract

TaN underlayers for spin valves were studied, which were deposited directly on top of Si substrates. The experimental results obtained with the TaN underlayer were compared with those obtained with other (Ta, Mo, and MoN) underlayers. The spin valve structure was Si/Underlayer(tÅ)/NiFe(21 Å)/CoFe(28 Å)/Cu(22 Å)/CoFe(18 Å)/IrMn(65 Å)/Ta(25 Å). The TaN underlayer for a spin valve element exhibited good adhesion to the Si substrate. The XRD patterns of the annealed TaN on bare Si substrate at 900 °C showed no Ta silicide phases, which suggests that the TaN layer may also be used as a diffusion barrier between Si substrate and the ensuing spin valve active layers, as well as an underlayer. A spin valve element having TaN underlayer deposited directly on top of a Si substrate showed a high MR ratio of about 8.3% after annealing at 200 °C. It is concluded that it is advantageous to use a TaN underlayer if one wants to fabricate spin valve elements directly on top of Si substrates.

Keywords: Spin valve; TaN underlayer; Si substrate

1. Introduction

Highly sensitive and high-power spin valve devices with a giant magnetoresistance effect have been used in reproducing heads for hard disk drives [1,2]. Now, spin valve devices are actively being considered for various applications in the field of biology and biomedical engineering as well as general magnetic field sensors [3,4].

To fabricate spin valve sensors on a Si substrate, a diffusion barrier is used between the Si substrate and an underlayer [5,6], which is often a SiO_2 layer. Ta layers have been widely used as the underlayer of spin valve sensors. Since some nitride layers are effective diffusion barriers, well known in the field of semiconductor devices, they could be used as underlayers as well as diffusion barriers if they have good enough magnetic and thermal properties, thus eliminating SiO_2 layer on the Si substrate.

In this work, TaN underlayers were mainly studied to find out whether they are effective underlayers for spin valves fabricated directly on top of a Si substrate. Some of the results obtained with TaN underlayers were compared with those obtained with Ta, Mo and MoN underlayers.

2. Experimental

Spin valve structures of Underlayer(tÅ)/NiFe(21 Å)/CoFe(28 Å)/Cu(22 Å)/CoFe(18 Å)/IrMn(65 Å)/Ta(25 Å) were deposited directly on top of bare Si substrates by using a DC magnetron sputtering system. Base pressure was less than 1.5×10^{-7} Torr and the working pressure of sputtering gas was 6 mTorr. N_2 gas flow rate during the TaN film deposition varied from 1 to 12 sccm when the Ar gas flow rate was about 130 sccm. To obtain a magnetic anisotropy, 600 Oe of magnetic field was applied to Si substrates during the magnetic film deposition. High-temperature annealing of underlayer films was carried out for 1 h. Annealing of the spin valve structure was performed from 150 to 350 °C for 60 min, each, sequentially at a pressure of 5×10^{-4} Torr in a magnetic field of 2 kOe.

Surface roughness of the TaN underlayers was measured with an atomic force microscope (AFM) and the film

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*Corresponding author. Tel.: +82 28200636; fax: +82 28217653.
E-mail address: jschul@ssu.ac.kr (S. Jo).

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thickness by a surface thickness profilometer. To measure adhesion between the TaN underlayer films and the Si substrate, a CSEN scratch tester was used. The film crystalline structure and texture were measured using an X-ray diffractometer (XRD). Magnetoresistance (MR) ratio and exchange coupling field (H_{ex}) of spin valve structures were measured by a four-point probe with an applied DC magnetic field of up to 1000 Oe. All the measurements were carried out at room temperature.

3. Results and discussion

Shown in Fig. 1 are deposition rates of Ta(N) underlayer films depending on N_2 gas flow rates during deposition. The deposition rate was 105.0 Å/min for Ta film and decreased to 95.2 Å/min for TaN films deposited with 1 sccm of N_2 gas flow rate. The deposition rate decreased further and reached 84.6 Å/min with 5 sccm of N_2 gas flow rate.

Fig. 2 illustrates resistivity and surface roughness of Ta(N) films as the N_2 gas flow rate varied from zero to 5 sccm during the film deposition. The resistivity of Ta(N) film was 245.1 μΩ·cm with no N_2 gas flow, and increased to 377.0 and 601.5 μΩ·cm as the N_2 gas flow rate was increased to 3 and 5 sccm, respectively. The RMS surface roughness of Ta(N) film was 2.24 Å with no N_2 gas flow, decreased somewhat to 2.15 Å at 3 sccm and then increased to 3.5 Å at 5 sccm of N_2 gas flow rate. The resistivity increases due to N incorporation into Ta layer. Since surface roughness does not increase up to 3 sccm of N_2 gas flow rate, it is expected that the interface smoothness of ensuing spin valve layers and, therefore, H_{ex} would not be adversely affected as the N_2 gas flow rate is increased up to 3 sccm.

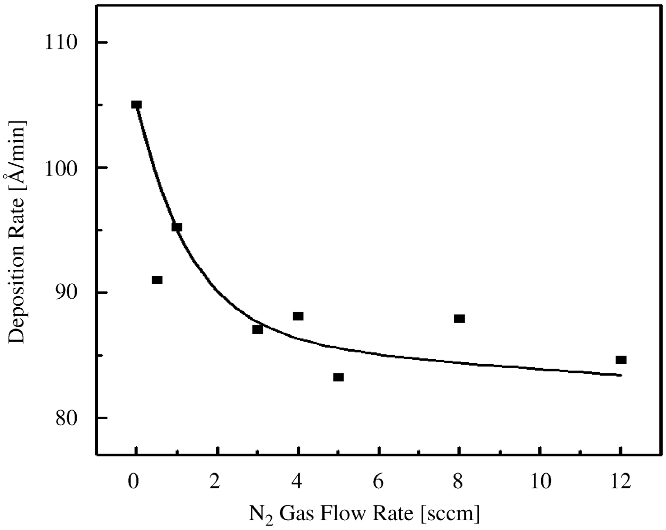

Fig. 1. Deposition rate of Ta(N) underlayer films as a function of N_2 gas flow rate.

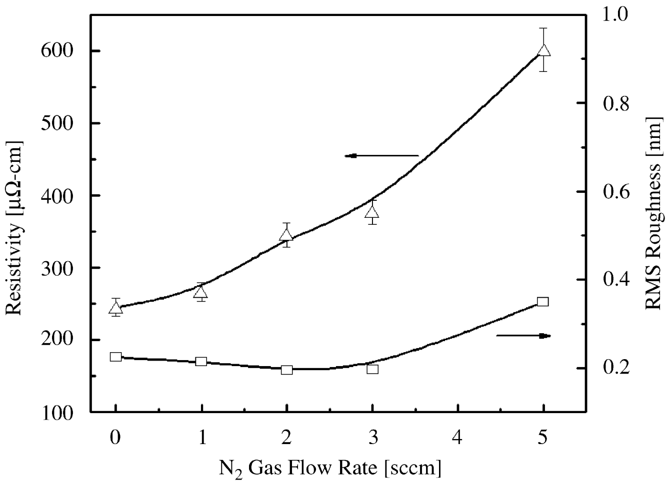

Fig. 2. Resistivity and RMS roughness of Ta(N) underlayer films as a function of N_2 gas flow rate.

Figs. 3(a) and (b) show scratch test photographs and an acoustic emission loadgraph of Ta(N) films, respectively, as the N_2 gas flow rate was increased from 0 to 2.0, 4.0 and 8.0 sccm. As the N_2 gas flow rate was increased, the force needed to scratch the film started to increase. As shown in Fig. 3(b), the adhesion force was 5 N for Ta film, and increased to 7, 9 and 10 N as the N_2 gas flow rate was increased to 2.0, 4.0, and 8.0 sccm, respectively. The adhesion force is doubled to 10 N when the TaN underlayer is deposited with 8 sccm of N_2 gas flow rate, compared with that of the Ta underlayer. As the incorporation of N into the TaN layer is increased, the adhesion property of the TaN underlayer becomes even better.

Figs. 4(a) and (b) show XRD patterns of Ta and TaN underlayers, respectively, deposited directly on top of Si substrates. The Ta and TaN films underwent the annealing process at 700 and 900 °C for 1 h each. The N_2 gas flow rate was 3 sccm during the TaN underlayer deposition for Fig. 4(b). As shown in Fig. 4(a), $TaSi_2$ phase appeared after 700 °C of annealing and TaSi, $TaSi_2$, Ta_5Si_3 phases appeared after 900 °C of annealing, which indicates interdiffusion between the Ta underlayer and the substrate. However, no silicide peaks were observed in Fig. 4(b), which indicates that interdiffusion between the TaN layer and the Si substrate did not take place even after 900 °C of annealing. The results show that TaN film is much more thermally stable than Ta film. Therefore, TaN film can be used as an effective diffusion barrier between Si substrate and ensuing active spin valve layers as well as an underlayer for a spin valve element.

Figs. 5(a) and (b) show MR ratio and H_{ex} of spin valve structures for various underlayer materials as a function of underlayer thickness from 7.5 to 47 Å. MR ratio and H_{ex} of spin valve structures fabricated without underlayers are indicated on each vertical axis of Figs. 5(a) and (b). The N_2 gas flow rate was 1 sccm for nitride underlayers. Thickness variation of MR ratio and H_{ex} for all the underlayers does not seem great for most of the film thicknesses considered. MR ratio and H_{ex} do not deteriorate as the thickness of the