Materials Science in Semiconductor Processing 14 (2011) 278–286

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Dry etching of magnetic tunnel junctions monitored by spectroscopic reflectance

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ARTICLE INFO

Available online 1 June 2011

Keywords:
Ion beam etching
Spectroscopic reflectance
Optical simulation
Thin film
Magnetic tunnel junction
Sputtering yield

ABSTRACT

The dry etching of magnetic tunnel junctions $Co/Al_2O_3/Co/Ni_{80}Fe_{20}$ was monitored using spectroscopic reflectance. Optical simulations show that the etching of a 2 nm thick layer of alumina is observable on the reflectance curves. It is then confirmed experimentally, by determining the chemical nature of the layer by Auger Electron Spectroscopy at different points of the reflectivity curves. We are then able to stop the etching process precisely in the thin barrier of alumina and in the lower electrode of cobalt. Thereafter, we have calculated the sputtering yield of each thin film, thanks to the simulations of the reflectance curves.

1. Introduction

Today, the dry etching is a required step in the Microelectronic industry. In a case of multilayers, it is necessary to control this process in order to stop it precisely in the targeted layer. A Magnetic Tunnel Junction (MTJ) is a good example [1–3]. This structure is generally composed by two ferromagnetic layers (Co, $Ni_{80}Fe_{20}$) separated by a thin insulating layer (Al_2O_3). For further electric measurements, a patterning process is used to design the two required electrodes [4]. However, the first stages need a precise control of the dry etching. For example, monitoring can be carried out by a secondary ion mass spectrometer (SIMS) [5]. However, on an existing etching tool, the installation of a SIMS can be problematic and expensive: modification of the vacuum chamber and the need of a differential pumping. In addition, detection needs a certain amount of secondary ions ejected from the sample during the etching process. Thereby, a SIMS can be useless if the etched surface is very small or if the etching uses an ion beam at a low energy.

A different option is the optical monitoring. Indeed, an optical diagnostic can be easier to install on an existing etching tool. Moreover, optical monitoring generally needs a small surface of the etched zone. A well-known method for endpoint detection is laser interferometry [6]. This technique relies on the interference phenomenon between the light reflected by the etched layer and by the substrate after transmission. Thus, the amplitude of the reflected light oscillates due to constructive and destructive interferences. The oscillations cease when the layer is fully etched.

A complementary method for controlling the etching is laser reflectometry. This technique detects the change of the reflectivity coefficient of the surface during its etching. This technique was successfully used for the monitoring of the etching of magnetic thin films [7], of III–V heterostructures [8], and Nb/Al_2O_3–Al/Nb stacks for the fabrication of Josephson circuit [9]. However, the monitoring of magnetic tunnel junctions during the etching was never reported with a comparable method.

This is the first point of this paper. The spectroscopic reflectance was investigated as endpoint detection for the etching process of magnetic tunnel junctions. The studied structures were stacks composed of $Co/Al_2O_3/Co/Ni_{80}Fe_{20}$. The objective was to control the etching until the lower electrode of cobalt. We prove in this study that the spectroscopic reflectance is a believable method for endpoint detection during the etching of magnetic tunnel junctions and very useful for MRAM applications.

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doi:10.1016/j.mssp.2011.05.008

The second point of this paper is the calculation of the sputtering yield of each layer, thanks to the optical measurements. For these calculations, we have taken into account the density and the surface binding energy of the thin films.

2. The experimental setup

The detailed composition of the studied stacks is the following: Si/SiO_2/Co(15 nm)/Al_2O_3(2 nm)/Co(2 nm)/$Ni_{80}Fe_{20}$ (15 nm)/Au(3 nm). The layers were deposited by ion beam sputtering. The deposition process of the stacks is addressed in a previous study [10].

Fig. 1 presents the experimental etch tool. Dry etching is performed with an argon ion beam in an ultra-high vacuum chamber with a residual pressure of 10^{-9} mbar. The ion beam is produced by a microwave source developed in our institute [11]. The ion beam is neutralized to avoid the charge effect during the etching of the insulating barrier.

In order to control the etching depth, the system is equipped with the spectroscopic reflectance. The light source emits in the visible spectrum ($400\,\text{nm} \le \lambda \le 800\,\text{nm}$). The beam of light has an incidence angle of 40° and a diameter $\Phi = 1$ mm. The reflected beam is analyzed by an Ocean Optics spectrometer. This enables us to select the better wavelength according to the material. We do use a non-polarized light for the monitoring of the etch process. Due to the optical configuration, the etching is performed with a normal incidence on a surface of $11 \times 11\,\text{mm}^2$.

Before any experimental etching, some optical simulations were performed to predict the reflectance evolution according to the stack thicknesses.

3. The thin films reflectance

In the case of two interfaces like a thin film deposited on an infinite substrate, the complex reflection coefficient r_{123} can be calculated according to the following equation [12]:

$$r_{123} = \frac{r_{12} + r_{23} e^{(i\beta_2)}}{1 + r_{12} r_{23} e^{(i\beta_2)}} \quad (1)$$

where

$$\beta_2 = \frac{2\pi}{\lambda} \tilde{n}_2 d \cos\theta_2 \quad (2)$$

This complex coefficient of reflection is functions of the thickness d of the top layer. The coefficient r_{12} is the complex reflection coefficient between the top layer and the void. As for the term r_{23}, it designates the complex reflection coefficient between the top layer and the substrate. The term ñ refers to the complex optical index of the considered layer such as

$$\tilde{n} = n + ik \quad (3)$$

with n the refraction index and k the absorption constant. For a multilayer, the substrate is then assimilated to the whole films localized below the top layer. The complex reflection coefficient can be thus calculated using the Abeles matrix [13].

So according to Eq. (1), the reflectance varies with the stack thickness during the etching. However, a variation of the reflectance can be very difficult to detect if the stopping layer is very thin. Consequently, the risk of overetching exists. In addition, the optical transition between two materials can be difficult to see if their optical indexes are very close. Thus, the two layers can be assimilated to only one. A previous study has estimated the accuracy of a comparable technique better than 5 nm for the etch depth [7]. Concerning the resolution, the best result reported is the real time monitoring of the etching of a 0.5 nm thick layer of InGaAs [14].

To have a first preview of the results, the comportment of reflectance was simulated according to the thickness of the different films. The reflectance simulations were performed with the software WinElli 4.08 [15]. Since the program did not have the optical indexes of $Ni_{80}Fe_{20}$,

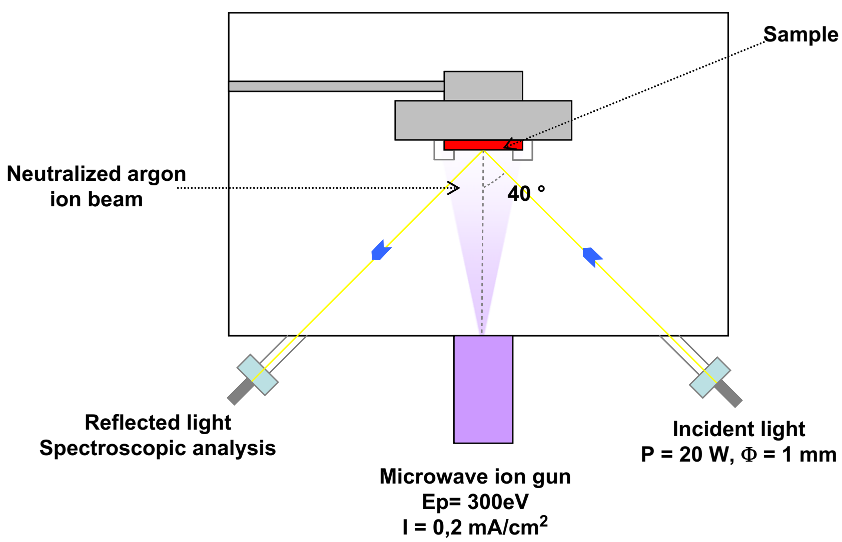

Fig. 1. Schematic view of the etching tool equipped with the spectroscopic reflectance.