Composition and Thickness of RF Sputtered Amorphous Silicon Alloy Films

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Abstract: Because the composition and the thickness of the thin films are very important for the fabrication of the devices, in this study we have undertaken the determination of the composition and the thickness of the RF sputtered amorphous silicon alloy thin films deposited at room temperature under very different preparation conditions by using various techniques. Incorporation of argon is demonstrated in the room temperature deposited films and the thickness of the films measured by different methods such as Rutherford backscattering, spectroscopicellipsometry and step-profiler are found to be in reasonable agreement with each other.

Keywords: amorphous Si alloys, Sputtering, RBS, Ellipsometry

1 Introduction

Amorphous silicon and silicon based binary alloys have generated a lot of interest both fundamentally and technologically and have assumed great importance in the fabrication of electronic, opto-electronic, photo-voltaic as well as sub-micron devices [1-17]. Low temperature deposition and the precise control of the composition as well as the thickness of the desired films are very much essential for the fabrication of the devices. Low temperature deposition of the thin films is necessary to eliminate the problems like increased probability of defect formation and dopant redistribution associated with high temperature processing. Accordingly, low temperature techniques such as plasma enhanced chemical vapor deposition (PECVD), various sputtering techniques (such as DC, RF, etc.) are being used for the purpose. Because the independent control of the constituent elements of the film is possible in sputtering, therefore, sputtering techniques are more desirable [9,18-20] for the deposition of the thin films of interest. Further, the precise control of composition and thickness of the thin films are necessary as the material properties of the films and the performance of the devices depends strongly on composition as well as on the thickness of the films [21-26].

In this work we have undertaken the determination of the composition and the thickness of room temperature deposited RF sputtered amorphous silicon and its alloy films, deposited under very different preparation conditions as well as gas ambient. The composition of the films have been obtained using Rutherford backscattering (RBS) while the thickness of the films are determined using RBS, spectroscopic ellipsometry (SE) and step-profiler. Incorporation of argon in the films deposited at room temperature is demonstrated and the thickness of the studied films as determined from very different techniques such as RBS, SE and step-profiler, are found to be in reasonable agreement with each other.

2 Experiment

The amorphous silicon alloy films studied here were prepared in a commercial high vacuum RF sputtering system (Leybold Z400). The RF sputtered deposition system was pumped by a combination of a mechanical and a turbomolecular pump to obtain a base pressure lower than $5 \cdot 10^{-5}$ Pa. A liquid nitrogen cold trap was used to reduce the partial pressure of water vapor in the residual gas. Different targets were used for depositing different varieties of films. High quality polycrystalline silicon was used as the target to prepare amorphous silicon films while high quality polycrystalline silicon and germanium as well as polycrystalline silicon and SiGe were used as target to deposit amorphous silicon germanium thin films. The details regarding the targets as well as the gas ambient is shown in Table 1. The targets were coupled to a RF generator (13.56 MHz) via the network for impedance matching between the generator and its load. Further, there is provision for mounting the substrate on a heated stage located 50 mm away from the target. The studied films were deposited at room temperature onto the crystalline silicon substrate and the bias of substrate was maintained at -50 V. Sputtering was done using high purity (99.999%) argon gas for the unhydrogenated samples while a mixture of high purity argon and hydrogen were used for the hydrogenated samples. Argon as well as hydrogen gas were fed continuously into the chamber by means of electronically controlled mass flow controller. The partial pressure of argon was maintained between 2-3 Pa while that of hydrogen was around 0.03 Pa. Pressure fluctuations, which influence the sputtering rate remarkably, were observed to be absent. A DC wall potential of 1500 V was applied on the targets. With these said parameters sputtering rates of 7 nm/min could be achieved. Before sputtering the substrates were cleaned by wet chemical process.

To determine the composition of the studied film, RBS measurements were performed using He ion beam of 2 MeV energy in a scattering chamber with a two-axis goniometer connected to a 5 MeV Van de Graaff accelerator. In the scattering chamber the vacuum was maintained to be better than $1x10^{-4}$ Pa. To reduce the hydrocarbon deposition, liquid N_2 cold traps were used along the beam path and around the wall of the chamber. Backscattered He^+ ions were detected using an ORTEC surface barrier Si detector mounted in Cornell geometry at scattering angle of 16.5^o. The beam current was measured by a transmission Faraday cup and the composition of the studied films were obtained by using the program developed by Kotai [27].

Because SE measurement is a precise, fast and non destructive technique, it was used to measure the thickness of the studied films. The ellipsometry data were obtained from a SOPRA spectroscopic ellipsometer of rotating analyzer type. All measurements were performed in air at room temperature for the wavelength ranging from 250-850 nm in steps of 5 nm at the angle of incidence of 70.2^o. The evolution of the SE spectra were performed by WVASE 32 software [28].

The thickness of the studied films were measured directly by the alpha-step-profiling equipment (Tencor 100). A small region of the sputtered surface was masked by the sample fixing apparatus and the step between the sputtered and non-sputtered region was scanned by the profiler and the thickness of the film was measured directly.

3 Results and Discussion

In this study we have investigated the composition and the thickness of the five different types of room temperature deposited samples, prepared under very different preparation conditions. Amorphous silicon films were deposited on Si substrates in argon ambient from a polycrystalline silicon target (#84) while another class of amorphous silicon films, contaminated with carbon (from the substrate kapton), were also deposited on Si substrate in argon ambient from a polycrystalline Si target (#126). Amorphous silicon-germanium films were deposited on Si substrate in argon ambient from poly-crystalline Si and Ge target (#155). Hydrogenated amorphous silicon germanium films were deposited on Si substrate in argon and hydrogen ambient from polycrystalline silicon and germanium targets (#136). Amorphous silicon-germanium films were deposited on a SiO_2/Si substrate in argon ambient from polycrystalline Si and SiGe targets (#71).

The composition and the thickness of the films were obtained from RBS spectra using RBX program developed by Kotai [27]. The composition and the thickness of the films obtained from the RBS analysis are shown in Table 1. This table also contain the thickness of the films as obtained from spectroscopic ellipsometry as well as measured directly from step-profiler.

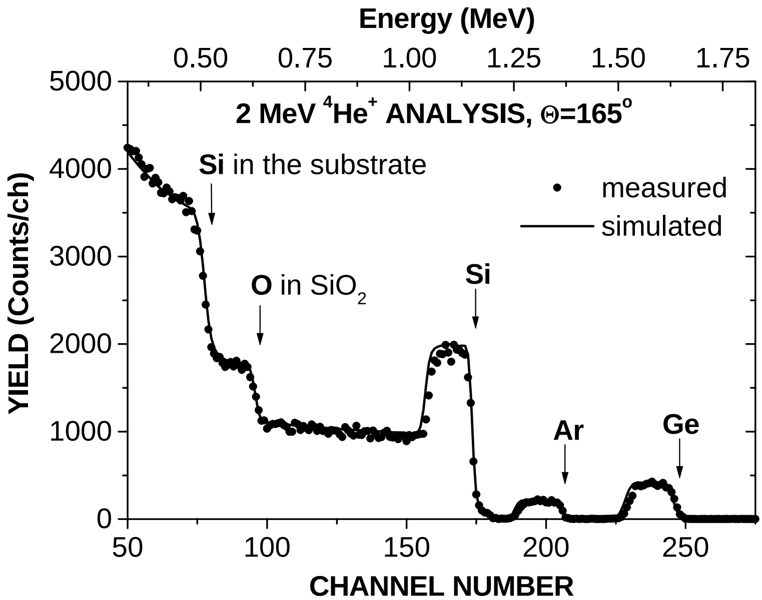

Figure 1
A typical RBS Spectra of amorphous silicon germanium film deposited on SiO_2/Si substrate along with the fit

Fig. 1 exhibits the typical RBS spectra of an amorphous silicon germanium thin film deposited on SiO_2/Si substrate (#71). The peaks arising from Si, Ge and Ar of the amorphous silicon germanium film are found to be well separated and each peak is further observed to have a relatively flat plateau indicating homogeneous distribution of elements in the film. Because the amorphous silicon germanium film (sample #71) was deposited on SiO_2/Si substrate not only oxygen edge from SiO_2 layer but also Si edge from the silicon substrate were also observed in the RBS spectra. Simulating the RBS spectra using RBX program, the areal density of the buried SiO_2 layer was estimated and using the density of SiO_2, the thickness of the buried SiO_2 layer is determined to be 10000 Å. The thickness of the said buried SiO_2 layer is also determined to be 10460 ±8 Å from the spectroscopic ellipsometry (SE), indicating reasonable agreement between the thickness as measured by RBS and SE. Similarly from the RBS analysis the thickness of the amorphous silicon-germanium layer for the sample #71 is found to be 2310 Å while the composition of Si, Ge and Ar are found to be 90.5%, 3.5% and 6% respectively. The composition and thickness of all the studied samples obtained from RBS analysis is shown in Table 1.

Table 1

sample #	Growth Parameters Target Gas	Thickness (A) Step Profile	RBS	SE	Composition Si/Ge/Ar/C
#84	p-Si Ar	1800	1800	1745	93.5/0/6.5/0
#126	p-Si Ar	5200	5000	-	84.7/0/6.8/8.5
#155	p-Si&Ge Ar	4000	3919	-	73.8/22.4/3.8/0
#136	Si&Ge Ar+H_2	10000	9961	-	73/22/5/0
#71	p-Si&SiGe Ar	2500	2310	2236	90.5/3.5/6/0

Because SE measurement is very effective and useful in determining the thickness of the films, we have also used SE to determine the thickness of an amorphous silicon germanium film (sample #71) as well as an amorphous silicon film (#84) for comparison with other measurements. The evaluation of the SE spectra have been done using WVASE 32 software. To simulate the SE spectra of the sample #71, the components used are air, surface roughness, semiconductor a-SiGe layer, silicon-dioxide layer and single crystalline Si substrate respectively. The roughness layer has been treated as a mixture of the layer material (a-SiGe) and 50% void. The effective medium approximation has been used for the purpose. The measured and the simulated spectra of the sample #71 is shown in Fig. 2. The thickness of the roughness layer, the amorphous SiGe layer and the silicon-dioxide layer are found to be 30, 2236 and 10460 Å respectively. Further, to simulate the the SE spectra of the sample #84, the components used are air, roughness layer, a-Si layer, single crystalline Si substrate respectively. The measured as well as the simulated SE spectra of the sample #84 are shown in Fig. 3. The thickness of the roughness layer and amorphous silicon are found to be 10 and 1745 Å respectively. The quality of the fit (mean square error (MSE)) for the samples #71 and #84 are found to be 11.2 and 9.2 respectively. The thickness of the two films (#71 and #84) as determined from SE spectra are also listed in Table 1. The thickness of the a-Si layer as well as the a-SiGe layer, determined from SE measurements and other measurements are found to be in reasonable agreement with each other.

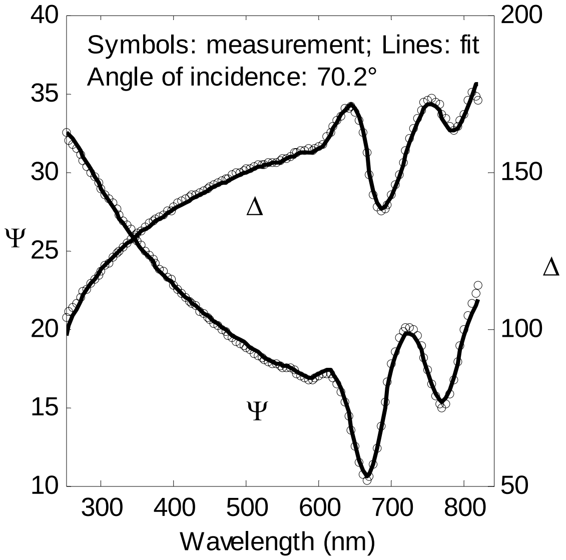

Figure 2
Measured (symbols) and simulated (solid line) ellipsometric spectra of amorphous silicon germanium film as a function of wavelength

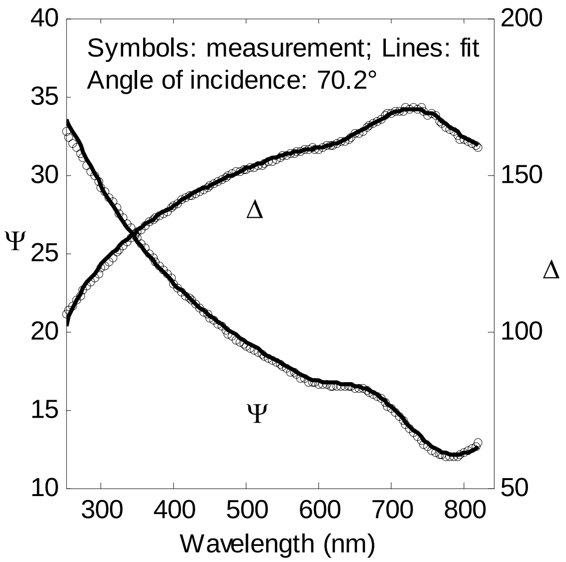

Figure 3
Measured (symbols) and simulated (solid line) ellipsometric spectra of amorphous silicon film as a function of wavelength

Conclusion

In this study we have deposited five different type of amorphous silicon based thin films, prepared at room temperature under very different deposition conditions and are also characterized by widely different techniques. The principal conclusion of the study are:

1 The RBS spectra and the composition analysis of the studied films clearly reveal the inclusion of Argon in the films deposited at room temperature.

2 The thickness of the studied films as measured directly by step-profiler and determined from RBS as well as SE analysis, are found to be in reasonable agreement with each other.

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