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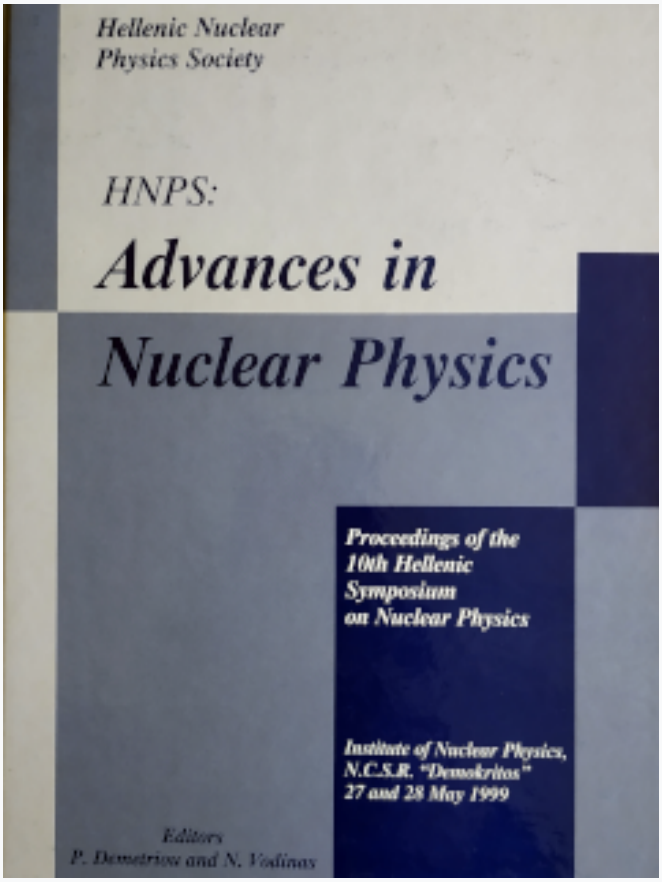

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Oxygen Contamination of Multilayer $TiN_x - SiO_2 - Si$ Structures found by Resonant RBS Analysis

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Abstract

Multi layer structures consisting of $TiN - SiO_2 - Si$ layers operating as MOS devices were constructed and tested for their electrical properties. RBS and resonance reaction analysis were performed for the characterisation of the structure of the devices. The results show a correlation between the structure found by RBS and the electrical performance of the devices.

1 Introduction

The Rutherford Backscattering Spectroscopy technique (RBS) has been established as a powerful tool of Ion Beam Analysis (IBA) in profiling and characterisation of multi - layer structures in a variety of materials [1,2,3]. In the present work, the RBS method was applied on the characterisation of materials consisting of layers of Titanium Nitride and Silicon Dioxide on a substrate of high purity n-type Si, in a Metal-Oxide-Semiconductor (MOS) arrangement. Titanium nitrides are novel class of materials which are characterised by metallic behaviour, low special resistivity, chemical stability and outstanding mechanical properties. They meet a lot of applications in modern electronics as electrodes for gates, diffusion barriers, ohmic junctions and restoring devices.

The samples were manufactured in the University of Thessaloniki using the reactive magnetron technique. A number of 10 MOS devices were fabricated

with different parameters of fabrication (polarisation potential of the substrate and temperature of development of the TiN film), in order to determine the optimum parameters for the best results. Measurements of the capacity and resistivity of the devices were conducted to correlate the manufacturing parameters with the electrical performance. Then, RBS measurements were carried out to correlate the structure of the device with the manufacturing technique and the electrical performance.

In a previous experiment [4], a number of $TiN - SiO_2 - Si$ samples were examined by Heavy Ion RBS, using a ^{12}C beam at energy $E = 10MeV$. The results showed that the TiN film was contaminated by a light element, which could not be identified in that experiment. In the present work, we examined the same samples with ^{4}He beam at energies around $3MeV$, in order to investigate the exact nature of that contamination.

2 The RBS Technique.

Rutherford Backscattering Spectroscopy is based on the simultaneous measurement of the energy loss of the projectile and the scattered particle and the reaction yield, after scattering at back angles ($\theta = 160° - 170°$). The energy of the beam is kept low enough as compared to the Coulomb potential between the projectile and the target so that the reaction mechanism is Rutherford type scattering. The width of the observed plateaux is related to the combined energy loss of the projectile and the scattered particle and leads to the determination of the thickness of the layer, while the yield is related to the concentration of the particular element.

The yield of the reaction is enhanced by the presence of a resonance in the compound nucleus of that system. In light systems, where the Rutherford scattering cross section is low, these resonances are frequent and well tabulate in the literature. If a resonance occurs, the reaction practically takes place only at the resonance energy and can be used for spatial localisation of the reaction, depth scan of the sample etc.

The $\alpha + ^{16}O$ has a resonance at $E_\alpha = 3.036MeV$ with a width of $24keV$, in which the scattering cross section is enhanced by a factor of 14 times above the Rutherford scattering level. We used this resonance to scan the TiN film and locate the presence of Oxygen, from the oxidization of Titanium.

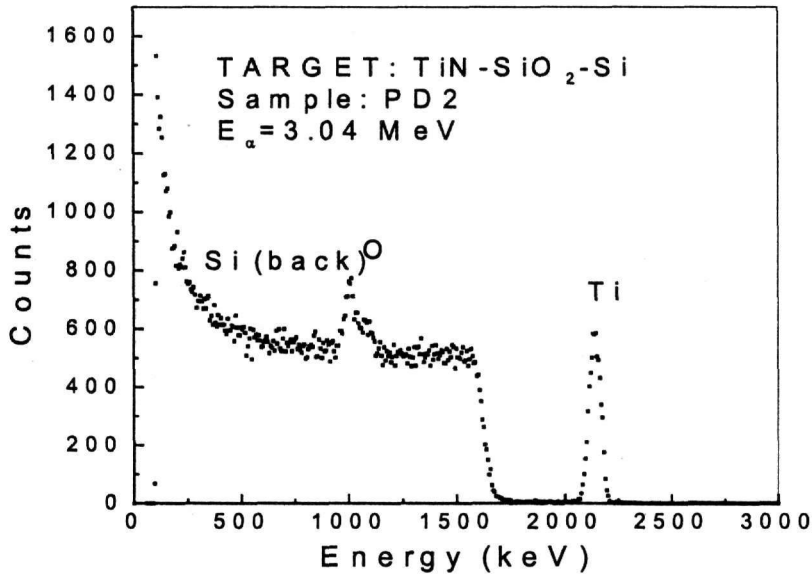

Fig. 1. Experimental spectrum of a $TiN - SiO_2 - Si$ structure at energy $E = 3.04MeV$.

3 Experimental procedure and results.

In the present work, we utilised a ^{4}He beam at energy 3.04 and $3.06MeV$ for the characterisation of the $TiN - SiO_2 - Si$ structures. The experiments were performed at the Nuclear Physics Laboratory of the NRCPS "Demokritos", using the TN11, $5.5MV$ terminal voltage accelerator. The detecting system consisted of a single Surface Barrier Si detector placed at angle $\theta = 160°$ with respect to the beam. The overall detector resolution was measured by scattering on a thin Au foil and found $\Gamma = 20keV$. The beam was well collimated using a two sets of beam collimators and kept at a size of $1 \times 1mm^2$.

At energy $E = 3.04MeV$, the $\alpha+^{16}O$ resonance is at the surface of the TiN film and therefore can provide information about the Oxygen contamination of the surface. A spectrum of the diode PD2, which is characterized by good electrical behavior, is presented in fig. 1. Since the energy of the beam is high and the thickness of the films is small (of the order of $1000\AA$), the energy deposited by the α-particles in the target is low as compared to the energy resolution of the detector. This leads to a poor depth resolution of the experiment.

The Titanium plateau from Rutherford Scattering is clear at the end if the spectrum. The "shoulder" of Silicon contained the SiO_2 film is comparable

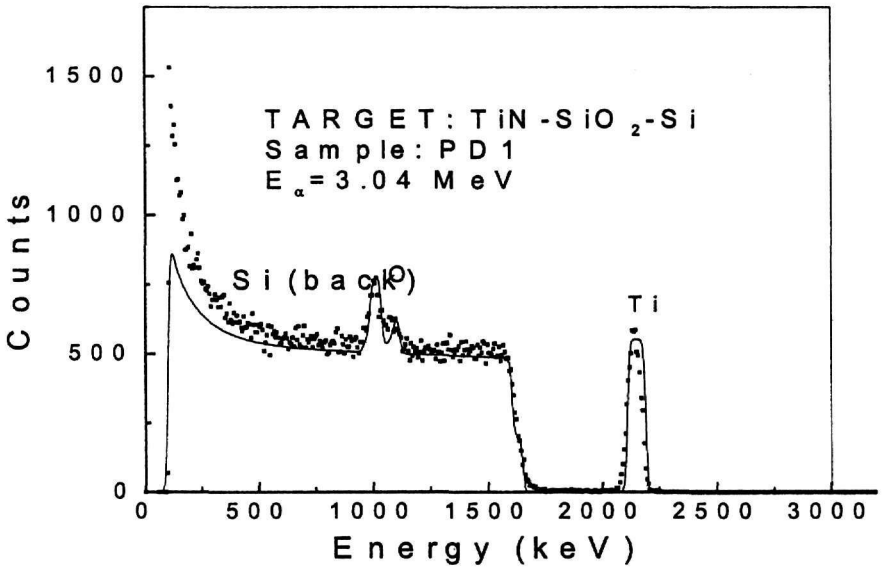

Fig. 2. Spectrum of the sample PD1 at energy $E = 3.04MeV$. The solid line represents simulation to the experimental spectrum.

to the depth resolution of the experiment and can barely be seen. There are two Oxygen peaks though sticking out of the Si backing continuum. The low energy one corresponds to the Oxygen contained in the SiO_2 layer and the high energy one corresponds to the Oxygen contamination of the TiN film. All samples were found to be contaminated by Oxygen, at a different level. The Nitrogen plateau is not seen, because it is very small and interferes with the O plateaus.

For the analysis of the spectra we performed simulations of the experimental spectra using the code LEFI, developed at the University of Ioannina [5]. Rutherford scattering plus resonance cross sections for the system $\alpha + ^{16} O$ were engaged in the simulations.

Figure 2 shows the experimental spectrum of the sample PD1, which is again characterized by good electrical behavior, together with the simulation (solid line). The simulation reproduces the experimental spectrum in a good way, under the assumption that the surface density of the TiN layer is $42\mu g/cm^2$ and the thickness of the SiO_2 layer is $22\mu g/cm^2$. The Oxygen contamination of the surface of the TiN film was determined at 7%. Contamination levels as high as 15% were found in other samples, which are characterized by poor electrical behavior.

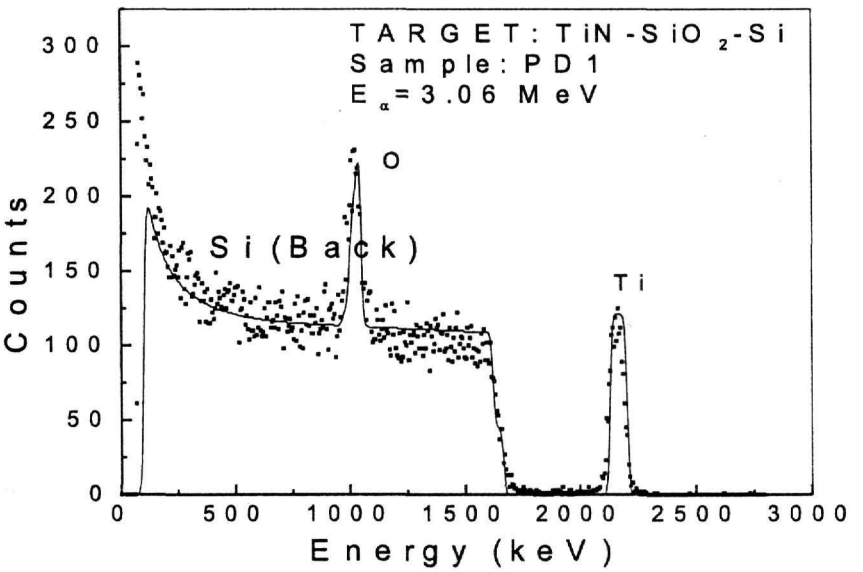

Fig. 3. Spectrum of the sample PD1 at energy $E = 3.06MeV$. The solid line represents simulation to the experimental spectrum. The data show no Oxygen contamination at the backside of the sample.

In a second experiment the energy of the beam was increased to $E = 3.06MeV$, thus placing the resonance at a depth of $25\mu g/cm^2$ inside the TiN film, thus investigating the backside of the layer. The experimental spectrum of the sample PD1 is shown in fig. 3. Only one Oxygen peak exists, corresponding the Oxygen contained in the SiO_2 layer and is well reproduced by the simulation under this assumption.

4 Discussion

A number of 10 MOS devices were manufactured and characterised by the Rutherford Backscattering Spectroscopy technique. The results show that samples with poor electrical behaviour suffered structural damage in the TiN layer. Also, samples with good layer structure were found to exhibit good electrical behaviour. The damage is be attributed to Oxygen contamination of the front side of the TiN film during fabrication. A correlation between the structure of the layers found by RBS and the deposition conditions used during fabrication, show that the best results were obtained when the devices were manufactured at room temperature with applied surface bias of -40 Volt.

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