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Micro-RBS study of nickel silicide formation

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Abstract

Two MeV He⁺ microbeam-Rutherford backscattering (μ -RBS) is used to obtain information on silicide formation in patterned nickel silicide samples under different annealing conditions. It is important to characterize silicide formation processes in such laterally non-homogenous samples in order to understand resistivity variations that are observed when metal oxide silicon field effect transistor (MOSFET) gate lengths are reduced, and when silicidation temperatures are changed. The patterned samples investigated consist of an array of square pads ($70 \times 70 \mu\text{m}^2$) of the structure Ni(Pt)Si_x/Poly-Si (2000 Å)/SiO₂ (2500 Å)/Si and narrow lines of 100 μm length and linewidths of 5 and 2 μm . μ -RBS ($\sim 5 \mu\text{m}^2$ beam spot) was used to obtain the thickness and stoichiometry of the silicide films for the square pads. The beam was focused to submicron dimensions for the scans over the narrow lines. μ -RBS results for the different silicide structures are presented and correlated with micro-Raman data. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The self-aligned silicide process (SALICIDE) is an extremely important factor when high performance complementary metal oxide semiconductor (CMOS) devices are scaled down because low sheet resistance of the source, drain and poly-silicon gate interconnection can be achieved. Silicides are used as local interconnects and as contacts in

CMOS technology. The silicide materials presently used, TiSi₂ and CoSi₂, are limited by problems of linewidth dependent sheet resistances and high leakage current in ultra shallow junctions, respectively. NiSi, a potential candidate to replace the above-mentioned silicides has been the subject of extensive investigation [1]. Much of the effort is channeled to investigating resistivity changes as metal oxide silicon field effect transistor (MOSFET) gate lengths are reduced or when silicidation temperatures are varied. The unique characteristics of NiSi include its low sheet resistivity, low contact resistance, low silicon consumption and low temperature one-step annealing. However,

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NiSi is thermally stable only up to 750°C, above which nucleation of the high resistivity phase NiSi₂ occurs. It is therefore important to investigate the phase formation of the nickel silicide (Ni₂Si, NiSi or NiSi₂) films.

RBS is an extremely versatile tool that can be used to characterize silicide formation. It provides a nondestructive means for the analysis of multi-layered structures. With the reduction of minimum feature sizes of integrated circuits (IC), analytical techniques such as RBS with a micron probe size are required. In this study, μ -RBS is performed on patterned nickel silicide samples that have been thermally treated under various annealing conditions. A 2 MeV He⁺ micro-beam is raster-scanned over the 70 × 70 μm^2 square pads and the narrow lines. Thickness and stoichiometric information of the films were obtained through the simulation of the spectra using the RUMP code [2]. These RBS results were subsequently compared with those from micro-Raman work.

2. Experimental

The substrates used were p-type Si (100) wafers. Undoped poly-Si was deposited by low pressure chemical vapor deposition (LPCVD) after a 250 nm thick oxide layer was grown by furnace oxidation. An array of square-shaped poly-Si pads 70 μm × 70 μm and narrow lines of 100 μm length with linewidths ranging from 5 to 0.35 μm were patterned. After patterning, nitride spacers were formed on the poly-Si sidewalls. Ni(Pt) films of 30 nm thickness were blanket-sputter deposited after a HF etch. Pt (~4 at.%) was added to delay the formation of NiSi₂, which is undesirable because of its higher resistivity [3]. The “as-deposited” samples were then annealed at temperatures ranging from 500°C to 900°C for 60 s in N₂ ambient. This is then followed by a selective etch to remove any unreacted metal.

RBS measurements using 2 MeV He⁺ ions were performed for compositional investigation. For the pad areas, the backscattered particles were detected at a scattering angle of 160° by a surface barrier detector with an energy resolution of 14 keV. The beam (with a beam spot of approxi-

mately 5 μm^2) was first scanned over the sample using a large scan size to obtain 2D RBS Ni map of the sample in order to identify the regions of interest. Once the regions are identified, the scan size was further reduced and the beam was raster-scanned on the pad area only. In order to analyze the narrow poly-Si lines, a beam well focused in the vertical-axis was raster-scanned across the vertically aligned lines. The beam intensity was maintained at ~100 pA and in order to obtain sufficient statistics, an average exposure time of ~4 h was required for the scans of the narrow lines. The spectra were recorded in a *list mode* format to allow off-line analysis. During the off-line analysis, RBS spectra were extracted from a region that was smaller than the narrow line in the RBS map.

The μ -Raman measurements in backscattering configuration were performed using a confocal spectrometer equipped with an Argon laser. The laser beam was focused to ~1 μm diameter spot and scanned over the pad and line areas. The spectra were obtained with 300 s integration time and 1.0 cm^{-1} spectral resolution.

3. Results and discussion

The Ni(Pt) silicide phase formed at different annealing temperatures was obtained through the simulation of the experimental RBS spectra. Fig. 1 shows the RBS spectra of the Ni(Pt) silicided poly-Si pad at annealing temperatures ranging from 700°C to 900°C. From the RBS simulation fit given in Fig. 2 (with depth uncertainty ~5%), the layer structure for the 700°C annealed sample was found to be Ni(Pt)Si–Si–SiO₂ with thickness of approximately 800–2000–2500 Å, respectively. As the annealing temperature increases, a reduction in the Ni peak height and a corresponding increase in the Si peak from the Ni(Pt) silicide were observed which indicate the transformation of the Ni(Pt) silicide phase. At high annealing temperatures of 800°C, tailing of the Ni and Pt peaks were observed at the low energy edge. This indicates the occurrence of agglomeration in the silicide layer, which is also observed by scanning electron microscope (SEM). Fig. 3 shows the RBS spectra at

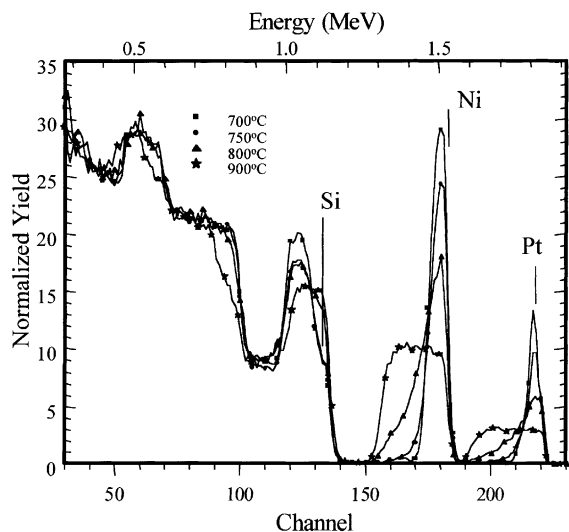


Fig. 1. RBS spectra for Ni(Pt) silicide pads at 700–900°C annealing.

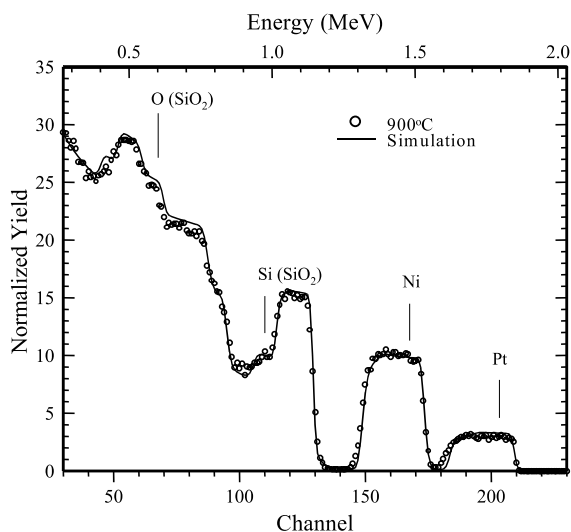


Fig. 3. Simulated and experimental spectra at 900°C annealing.

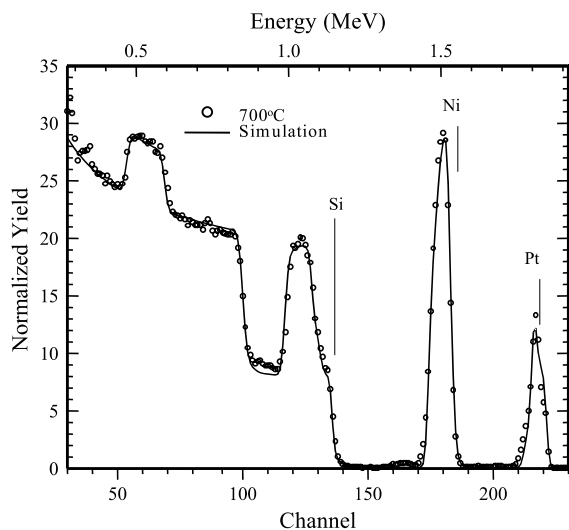


Fig. 2. Simulated and experimental spectra at 700°C annealing.

900°C annealing. The Ni and Pt peaks have broadened significantly and the Si step for the silicide layer is no longer present. A step can be observed in the O and Si peaks from the oxide (SiO₂) layer. The observations indicate the morphological changes of the silicide layer. The silicide morphology is affected by both interface roughening during the initial silicide formation and high

temperature treatments after silicide formation. Such morphological changes could be due to silicide agglomeration or silicide enhanced grain growth in the poly-Si [4]. RBS simulation has verified the presence of Si, Ni and Pt in the top layer with a concentration of Ni lower than that for NiSi₂. This may suggest the occurrence of mixed columns of poly-Si and Ni silicide or the formation of islands of NiSi₂ on poly-Si. The RBS spectra showing the transformation of the silicide phase are in good agreement with those obtained from the μ -Raman spectra.

The Raman spectra for Ni silicide pads at annealing temperatures from 700°C to 900°C [5] are given in Fig. 4. The NiSi Raman peak (at 215 cm⁻¹) was observed for samples annealed up to 800°C. As the annealing temperature increases, the NiSi Raman peak decreases. At 900°C, the NiSi Raman peak was no longer observed. The absence of the NiSi Raman peak can be attributed to severe agglomeration, poly-inversion or nucleation of NiSi₂ [5]. The significant increase in Si substrate peak intensity at 520 cm⁻¹ with increasing annealing temperature also indicates that agglomeration and poly-inversion had occurred. The weak NiSi₂ Raman signal makes its presence difficult to detect. From the simulation of the RBS spectra, the silicide phase can be easily identified and thus

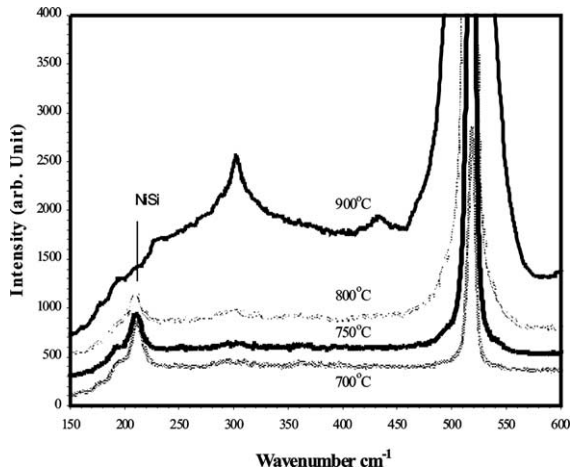


Fig. 4. Raman spectra for Ni silicide pads at annealing temperatures from 700°C to 900°C.

μ -RBS is an efficient complementary technique to detect the phase transformation and structural quality of silicide film.

The 2D RBS Ni map is shown in Fig. 5. Fig. 6 gives a comparison of the RBS spectra from the 700°C annealed Ni(Pt) silicide pad area and the 5 and 2 μ m narrow lines. The RBS spectra for the pad area and the 5 μ m line retain very similar structure. A comparison between the RBS spectra for the pad and the 2 μ m narrow line shows an obvious reduction in the Ni peak height and a slight decrease in the Pt peak height. The Si yield

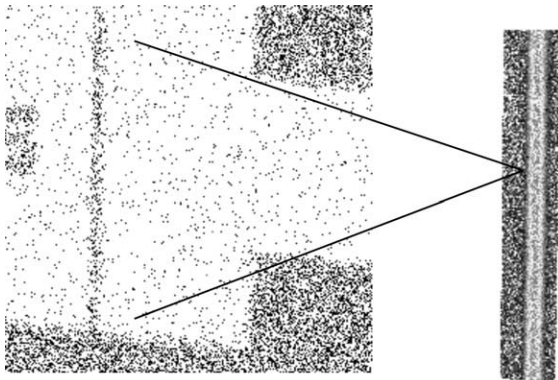


Fig. 5. 2D RBS Ni map of the pad and the 2 μ m line (100 μ m \times 100 μ m scan size).

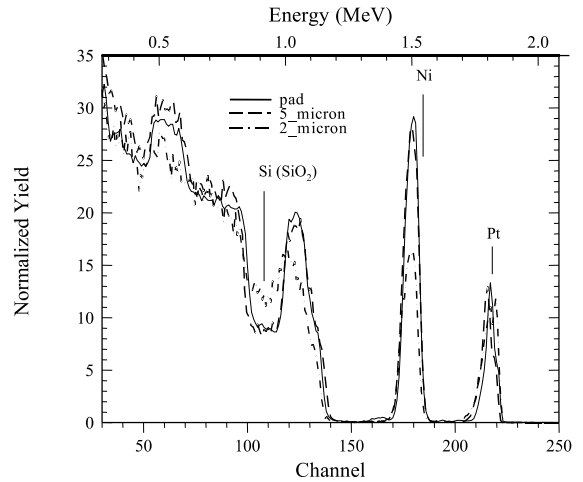


Fig. 6. RBS spectra for Ni(Pt) silicide pad, 5 and 2 μ m lines after 700°C annealing.

from the oxide (SiO₂) layer shows an increase by a factor of approximately 1.5 times as the linewidth is reduced from 5 to 2 μ m.

Using the list mode data collected for the 5 μ m line, an RBS spectrum was generated using a scan region slightly larger than that of the line. The spectrum of this new region, which encompassed both the line and a narrow strip of oxide (on both sides of the line) displayed a similar structure to that obtained for the scans on the 2 μ m line. From this observation, it can be deduced that a mixture of oxide and nickel silicide may be included in the RBS analysis. SEM micrographs of the 2 and 5 μ m lines are shown in Figs. 7(a) and (b), respectively. Some artifacts along parts of the 2 μ m line were observed, suggesting the presence of a mixture of silicide and oxide on the surface.

To investigate the possibility of beam-induced damage to the samples, spectra from the first 35% and the last 35% of the events of a long run were generated and compared. The RBS spectra obtained from both the 5 μ m and the 2 μ m narrow lines were essentially unchanged throughout the irradiation. This shows that damage done to the sample by the ion beam is insignificant in this case. Hence, μ -RBS is shown to be a very useful non-destructive technique in the study of silicide formation on patterned structures. Another useful application of μ -RBS is the investigation of

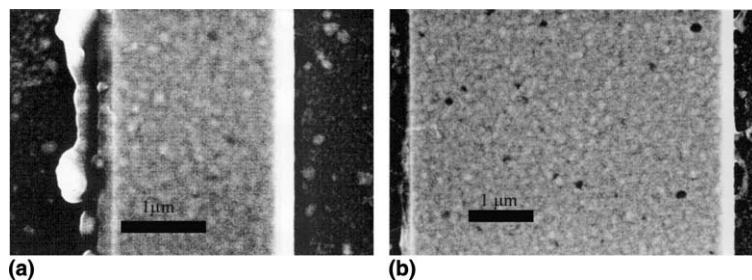


Fig. 7. SEM micrographs of the 2 (a) and 5 μm line (b).

uniformity of the silicide lines formation. A suitable scan size can be selected to specifically collect data along different lengths of the 100 μm narrow silicide lines. From the stoichiometric ratio obtained by fitting these $\mu\text{-RBS}$ data, one can then compare and quantify the uniformity of silicide formation along the 100 μm length. $\mu\text{-RBS}$ is thus a useful tool in the investigation on the suitability of the various silicide formation methods.

4. Conclusions

The technique of $\mu\text{-RBS}$ allows one the flexibility of selecting a small region of interest for analysis. The $\mu\text{-RBS}$ results demonstrate the feasibility of the technique to study the phase transformation and the structural quality of metal silicides on patterned structures. The data obtained from $\mu\text{-RBS}$ were found to correspond well

with those obtained using Raman spectroscopy. In addition, $\mu\text{-RBS}$ provides a direct method to study the silicide formation on narrow lines. Thus, $\mu\text{-RBS}$ is shown to be a viable and potent technique that can be applied in the study of nickel silicide formation.

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