International Journal of Thin Films Science and Technology

http://dx.doi.org/10.12785/ijtfst/040309

Ion Beam Synthesis of Cobalt Silicide Layers in Si(111)

Ayache Rachid [1,*], *Sidoumou Mohamed* [2] and *Kolitsch Andreas* [3]

[1]Pharmacy Department, University of Batna, Batna, 05000, Algeria.
[2]Physics Department, Faculty of Sciences, University of Blida, Blida, 09000, BP 270, Algeria.
[3]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, POB 510119, D-01314 Dresden, Germany.

Received: 12 Jun. 2015, Revised: 22 Aug. 2015, Accepted: 23 Aug. 2015.
Published online: 1 Sep. 2015.

Abstract: Thin $CoSi_2$ layers are formed by 195 keV Co ion implantation in Si(111) substrates to a dose of 2×10^{17} Co^+/cm^2 at room temperature (RT) followed by annealing in N_2 atmosphere at different temperatures during 1 h are investigated. The characterizations of the as-implanted and annealed samples are performed using Rutherford backscattering spectrometry (RBS) and X-ray diffraction (XRD). Also the obtained samples have been characterized by means of Raman spectroscopy. The results show that the $CoSi_2$ phase is polycrystalline with a random crystallographic orientation.

Keywords: Cobalt silicide; IBS; RBS; XRD.

1 Introduction

The study of transition metal silicides has attracted a great deal of interest for their applications as contact materials, gate electrodes, or interconnect materials in microelectronic devices [1-3]. $CoSi_2$ is of CaF_2 type structure, which is similar to that of Si. At room temperature, the lattice constant of $CoSi_2$ is 1.2% smaller than that of Si [4–6]. The Co atoms can possibly be ‘‘added ’’ into the Si lattice to convert Si to $CoSi_2$ structure with almost no volume change. Recently, silicide nanostructures have attracted increasing interest in nanoscale device applications. Thin silicide films have been tailored by ion bombardment of layered structures as well as by physical or chemical vapor co-deposition, pulsed laser deposition, and other thin film deposition methods [7–9]. In this work, we shall report on the results of our study of buried $CoSi_2$, layers formed in silicon by ion beam synthesis (IBS) with subsequent high-temperature annealing to remove the residual radiation damage and to redistribute the implanted species.

2 Experimental Details

A buried cobalt silicide layer was produced by 195 keV Co^+ ion implantation with a dose of $2x10^{17}Co^+/cm^2$at room temperature (RT) into a chemically cleaned p-type Si(111) wafer. The ion source is a DANPHYSIK high current implanter operated at 20-200 keV with magnetic scan and current limit less than 10 mA. When the implantation is completed, the samples are then annealed in N_2 atmosphere at different temperatures in the range of 600-1000 °C during 1h.

Rutherford backscattering spectrometry (RBS) was performed on the as-implanted and annealed samples with 1.7 MeV He^+ ions at the scattering angle of 170° between the incoming and outgoing beam line. The experimental spectra were analyzed by SIMNRA computer program [12]. XRD measurements were performed in a θ-2θ geometry using CuK_α radiation. Furthermore, the obtained samples have been characterized by Raman spectroscopy.

3 Results and Discussion

Figure 1shows the random RBS spectrum of the annealed sample at 600°C during 1h implanted with high current density confirming the formation of the silicide, as the spectrum shows a clear step just behind the Si leading edge. The arrows (labeled Co and Si) indicate the energy for backscattering He^+ ions from these elements at the surface. The SIMNRA simulation of RBS spectrum allows the determination of the depth profile of Co and Si elements (see inset, figure 1) and the confirmation of the formation of thin $CoSi_2$ buried layer ($40x10^{15}atms/cm^2$). The SIMNRA simulation of RBS spectrum indicates the existence of pure Si layer at the sample surface. Also the depth profiles of Si and Co elements (not shown) obtained by SIMNRA confirm the formation of buried $CoSi_2$ layer ($7x10^{15}atms/cm^2$) during the ion implantation (for the as-implanted sample).

Figure 2 shows the RBS spectra of the as-implanted and annealed samples. It can be seen that by increasing the temperature treatment, the height of Co signal decreases

*Corresponding author E-mail: ayache_r@yahoo.fr

© 2015 NSP
Natural Sciences Publishing Cor.

whereas the energetic width increases, at the same time, the Si signal around, channel 520, corresponding to $CoSi_2$ layer is extended.

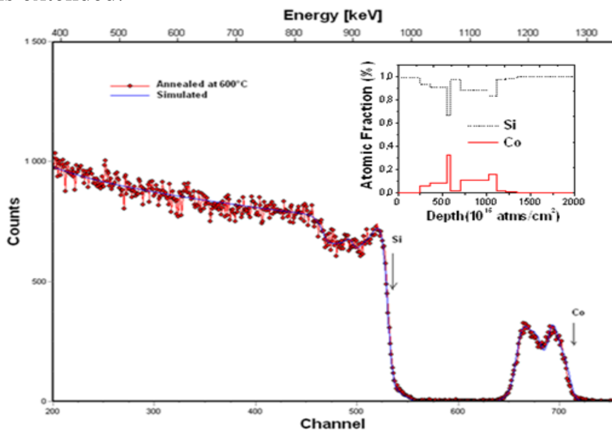

Figure 1: Random RBS data for the annealed sample at 600°C during 1h. Inset Co and Si depth profile deduced from RBS spectrum.

Also the heat treatment leads to the diffusion of oxygen from the surface to the interior of Si substrate. XRD was performed to investigate the formation of the Co silicide phases and Si crystal orientation.

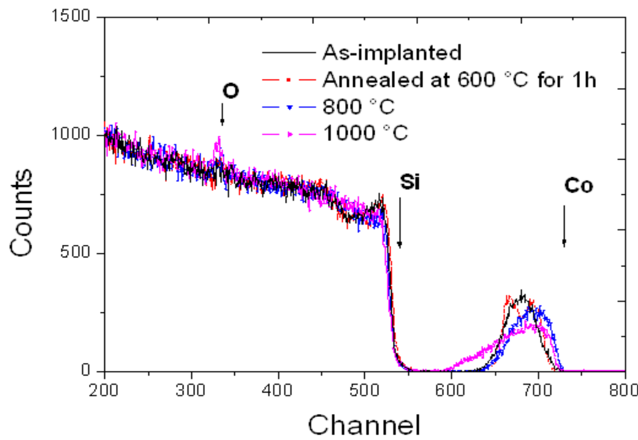

Figure 2: RBS spectra for the as-implanted and annealed samples at different temperatures for 1h.

Figure 3 is a XRD spectrum showing Si peaks from Co-induced poly-Si films. Si peaks of (1 1 1), (2 2 0), and (3 1 1) were observed at 28.628, 47.68, and 56.388, respectively.

During annealing at different temperatures in the range of 600-1000 °C for 1 h, X-ray-diffraction measurements show diffraction peaks of the $CoSi_2$ phase. From this, it can be concluded that ion implantation of such a high fluence at RT produces an amorphous layer of Si mixed with the implanted Co atoms. This layer does not recrystallize epitaxially but rather in a polycrystalline form with a more or less orientation of the crystals; the $CoSi_2$ phase is polycrystalline with a crystallographic orientation determined by the random orientation of Si crystals. This is a heteroepitaxial Si film growth above the $CoSi_2$ layer. This is due to a small lattice mismatch between Si and $CoSi_2$ [13].

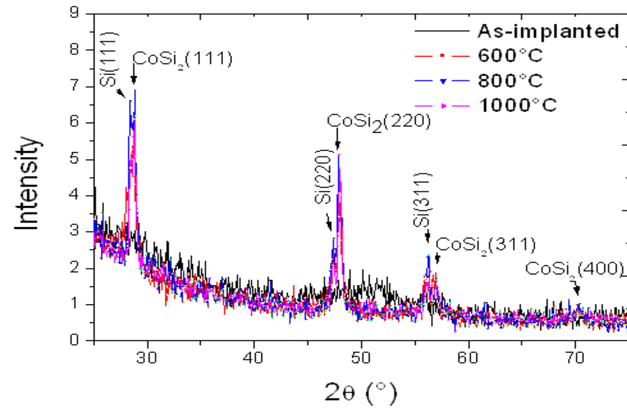

Figure 3: XRD patterns of the as-implanted and annealed samples for different annealing thermal.

Raman peaks of the cobalt silicide layer formation are shown in Figure 4 in the range of 200–600 cm^{-1}.The first order Raman spectrum of crystalline Si is characterized by the presence of one peak corresponding to the only Raman active phonon that is allowed by the crystal symmetry. This peak has a Lorentzian shape, centered at a wavenumber of 520 cm^{-1} with a full width at half maximum (FWHM) of about 3 cm^{-1} at room temperature.

As shown in Figure 4, two clear bands at 300 and 325 cm^{-1} can be observed. With the increase of temperature from 600 to 1000°C, the intensity of the band at 300 cm^{-1} gradually increases. The shift peak of Si at ~468 cm^{-1} in the as-implanted sample related to the damage induced during the ion implantation of cobalt into a silicon substrate.

Inset Figure 4 shows the variations of the Raman peak intensities of the band at 520 cm^{-1} of the as-implanted and annealed samples with varying temperatures. Upon post-thermal annealing, the damage in the Si substrates and $CoSi_2$, films decreases gradually. A small Raman peaks at ~325 cm^{-1} are attributed to the one-phonon LO vibration mode of $CoSi_2$ is observed as well [14].

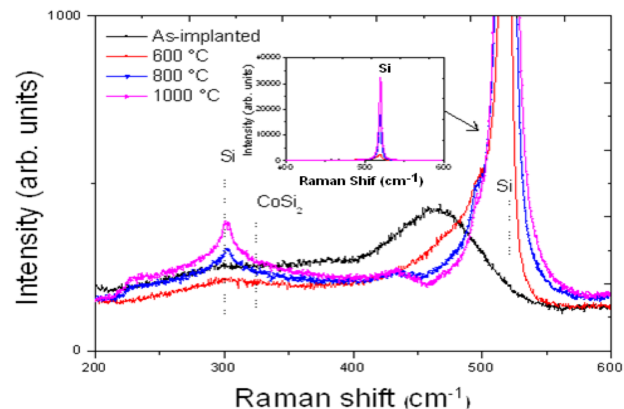

Figure 4: Raman scattering spectrum at RT for the as-implanted and annealed samples.

© 2015 NSP
Natural Sciences Publishing Cor.

4 Conclusion

Implantation of 195 keV Co^+ with a dose of $2x10^{17}$ at./cm^2 in Si(1 1 1) substrates at room temperature followed by annealing in an N_2 atmosphere at different temperatures during 1 h allows the formation of a continuous buried $CoSi_2$ layer. The $CoSi_2$ phase is polycrystalline with a randomly crystallographic orientation. The Raman peak intensities of the band at 520 cm^{-1} increase after annealing by thermal reflection of the recrystallization of silicon substrate.

Acknowledgments

We acknowledge the technical assistance of the IBC team at Helmholtz-Zentrum. Special thanks go to Mrs. Scholz for the XRD measurements and Mrs. Lucchesi for her help with Raman spectroscopy.

References

[1] L.J. Chen and K.N. Tu, Mater. Sci. Reports. **6** (1991) 53-140.

[2] S.P. Murarka, J. Vac.Sci.Technol. **17**(1980) 775-792.

[3]Karen Maex, Materials Science and Engineering,**Rll** (1993) 53-153

[4]O. P. Karpenko, S. M. Yalisove, J. Appl. Phys.80, **11** (1996) 6211-6218

[5] A. Vantomme, M.A.Nicolet, N. David Theodore, J. Appl. Phys. **75** (1994) 3882-3891.

[6] P.A. Bennett, D.J. Smith, IK. Robinson, Applied Surface Science **180**(2001) 65-72

[7] S. Bocelli, G. Guizzetti, F. Marabelli, G. Thungstriom, C.S. Petersson, Applied Surface Science **91** (1995) 30- 33.

[8] M. Novakovic, M. Popovic, K. Zhang, K.P. Lieb, N. Bibic, Applied Surface Science **295** (2014) 158-163

[9]D. Smeets, J. Demeulemeester, D. Deduytsche, C. Detavernier, C. M. Comrie, C. C.Theron,C. Lavoie, A. Vantomme, J. Appl. Phys. **104** (2008) 103538

[10] A.H. Reader, A.H. van Ommen, P.J.W. Weijs, R.A.M. Wolters, D.J. Oostra, Rep. Prog.Phys. **56** (1993) 1397-1467.

[11] A. Vantomme, M.F. Wu, U. Wahl, J. De Wachter, S. Degroote, H. Pattyn, G. Langouche, H. Bender, Nucl.Instrum.Methods B **120** (1996) 190–197

[12] M. Mayer, AIP Conf. Proc. **475** (1999) 541-544.

[13] G.Bai, M. A. Nicolet, J. Appl.Phys. 71, **2**(1992) 670-675

[14] B. R.Chakraborty, S. K.Halder, N.Karar, D.Kabiraj, D. K. Avasthi, J. Phys. D: Appl. Phys.**38** (2005) 2836-2840

© 2015 NSP
Natural Sciences Publishing Cor.