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Micro RBS Analysis by Focused 1.5MeV Ion Beam

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A micro beam line with 1.5 MeV helium ions for Rutherford backscattering (RBS) measurements of microareas has been realized. Piezo-driven objective slits and a magnetic quadrupole doublet were used as a demagnification system. A minimum spot sizes of 1.3 μm x 2.2 μm was obtained. Inner images of multilayered structures with gold lattices isolated with silicon dioxide were nondestructively obtained by an RBS mapping technique.

1. Introduction

Conventional RBS measurements with a beam spot size of 0.5-1 mm have extensively been used for characterizing ion-implanted semiconductors[1]. In recent years, however, the feature size of processing fell down in ranges from several microns to submicron, and maskless processes, for example, ion implantation by focused-ion-beams (FIB)[2], focused ion or laser beam induced chemical processes[3], have intensively been studied. A microprobe for characterizations of such processes is required.

So far several groups have achieved RBS or PIXE analyzing systems with a MeV microbeam whose spot size is less than 3 μm. Two methods were used to realize a microbeam: one is simply to insert a small aperture in a beam line, through which only a small part of the beam passes onto a target[4]. The other is to combine an objective aperture and focusing lenses, where an imaginary ion source defined by the objective aperture is demagnified with focusing lenses onto a target[5,6]. Although the latter is much more complicated than the former, higher beam intensity with smaller beam spot size can be obtained by the latter.

In this study, a micro-RBS analysis system was realized with 1.5 MeV helium ion beams. The micro beam was formed by inserting piezo-driven objective slits and a magnetic quadrupole doublet in the beam line. A minimum beam spot size of 1.3 μm x 2.2 μm was obtained. RBS mapping images were obtained by scanning the beam, where the images of the inner layer of multilayered structures were nondestructively obtained, which cannot be done by secondary electron microscopy (SEM).

2. Experimental Procedures

A Van de Graaf accelerator supplies helium ions with an energy of 1.5 MeV and a current of several μA to an beam line after deflecting by 30 degrees in an analyzer magnet.

The beam line consists of objective slits, subsidary slits, scanning coils for vertical and horizontal directions, and a magnetic qudrupole doublet. Effective distances between the objective slits and the doublet and between the doublet and the target are 1846 mm and 135 mm, respectively. The beam line is evacuated down to 1 x 10^{-7} Torr by turbo molecular pumps.

The objective slit is formed by two pairs of collimator slits which are driven by the piezo-elements mounted on micrometers. The slit width is controlled manually in a range of up to 1000 μm by the micrometer and remotely to 30 μm by the piezo-element. The subsidary slit eliminates the scattered beam by the objective slit.

The focusing lenses for demagnifying the beam are a magnetic quadrupole doublet with a pole gap and length of 5 and 32 mm respectively. A maximum field gradient of the yield is 4.9 kG/cm. The combination of the objective slits and the quadrupole doublet gives rise to horizontal and vertical demagnification factors of 1/4.7 and 1/21.9, respectively.

Two pairs of scanning coils are attached before the lens system and deflect beams horizontally by 150 μm and vertically by 50 μm at the target surface for 1.5 MeV helium ions. A maximum scanning frequency is 100 Hz.

Figure 1 shows the data aquisition and beam scanning system. The target chamber has an optical microscope and three detectors: a

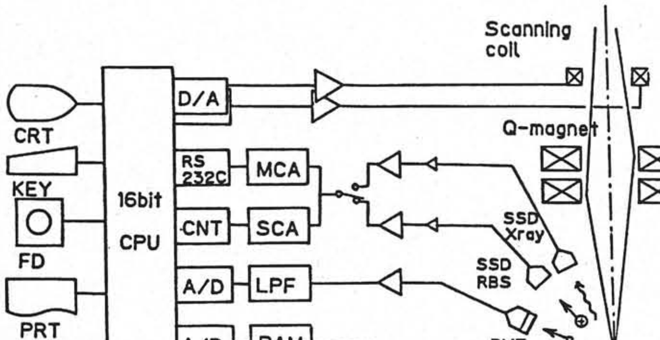


Fig. 1 Schematic diagram of the micro RBS analyzing system.

photo-multiplier-tube (PMT) coupled with a scintillator for secondary electrons, a surface-barrier Si solid-state-detector (SSD) with an energy resolution of 15 KeV for RBS and a pure Ge SSD for PIXE. The optical microscope with a magnification of 5 is used for the rough alignment of the beam to the target position by monitoring the fluorescence from a quartz plate. The Si SSD is located 30 mm away from the target with an angle of 45 degrees to the beam axis.

The SEM signal from PMT is fed into 12 bit A/D converter with a conversion time of 25 μsec. The beam current at the target monitored by a current integrator can be fed into A/D converter, too. The RBS signal from SSD is filtered with an energy window of the single channel analyzer (SCA) and collected by the computer controlled counter module with a time resolution of 1 μsec for RBS mapping. The SSD signal is also fed into the multichannel analyzer coupled with the computer for ordinal RBS measurments. Scanning coils are fully controlled by the computer through 12 bit D/A converter with a settling time of 20 μsec, by which beam positioning and scanning are possible.

RBS or secondary electron mapping data are stored in computer memories and displayed with 2700 pixels (90 x 30) in 7 or 14 step with different colors corresponding to event counts or secondary electron intensity. It takes 9 seconds to get one frame of a mapping images. This time duration is limited by the maximum frequency of the scanning coils.

3. Results and Discussion

The optimum coil currents for the quadrupole magnets which gave the maximum demagnification at a fixed target position were estimated by computer simulations of magnetic fields and resulting beam trajectories.[6] The beam spot size at the target was experimentally obtained by two different ways. One was to measure the exposed profiles on PMMA. The other was to estimate the beam pofile using the knife-edge method as described elsewhere[6].

In spite of the reduction of the object-slit width down to 20 μm for the horizontal axis and 90 μm for the vertical axis, the saturation in the beam spot size of about 1.3 μm for the vertical axis and 2.2 μm for the horizontal axis was observed[6]. The minimum spot size obtained in this system would be limited by several factors. They are lens aberrations, momentum spreads of the original ion beams, stray magnetic fields, forward scattering by the objective slits and mechanical vibrations.

The beam current density at the objective slit was about 10-20 $\mu A/cm^2$. The slit size of 60 μm x 8 μm which resulted in a beam spot size of 3 μm x 3 μm with a current of 50-100 pA at the target was selected for RBS mapping.

The RBS mapping of a multilayered structure was demonstrated and the image of the inner layer of a gold lattice which cannot be imaged by SEM images was obtained. Figure 2(a) shows the schematic diagram of the demonstrated substrate with the double layer structures of gold lattices of 30 nm thickness on a glass plate. The two lattices were isolated with sillcon dioxiside of 600 nm thickness. The first layer consists of a diagonally crossing pattern. The second lattice pattern was by 45 degree tilted in a plane.

Figure 2(b) shows the RBS spectrum measured by defocused beams. Two peaks of gold were observed at channels 180-220 corresponding to the first and second layers of gold lattices, respectively. The RBS mapping images were collected by adjusting the energy window of SCAs at the two peaks. Figure 2(c) shows the RBS mapping image with the higher energy window, indicating the diagonally crossing lattice pattern corresponding to the first gold layer. Figure 2(d) shows the RBS mapping image with the lower energy window, indicating the second gold layer. The result obtained in Fig.2(d) cannot be obtained nondestructively by SEM or Auger, where successive layer removals by sputtering must be used. It took about 1 hour to acquisit data with an ion current of about 100 pA.

The degradiation of the mapping image of the second gold lattice is probably due to the peak energy shift of the RBS spectrum by the defocused beam shown in Figure 2(b). It is considered that the beam path depends on the position of the lattice pattern, which gives rise to the energy shift of back scattered particle. The detecting system geometry including the beam axis and the SSD position, thus, must be considered to understand the mapping image of multilayered structures. Further investigation on this point is now on progress.

4. Conclusion

A micro beam line with 1.5 MeV helium ions for RBS measurements has been realized by piezo-driven objective slits and a magnetic quadrupole doublet with demagnification factors of 1/21.9 (vertical) and 1/4.7 (hori zontal). A minimum beam spot size of 1.3 μm x 2.2 μm was obtained. The computer controlled data aquisition and beam scanning system made it possible to get secondary electron and RBS mapping images. Multilayered structures with gold lattices isolated with silicon dioxide were, for the first time, nondestructively analyzed.

References

1) Backscattering Spectrometry, ed. by W.K. Chu, J.W. Mayer and M.A. Nicolet (Academic Press, New York, 1978)

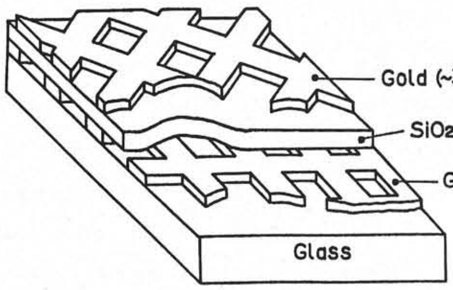
2) T. Shiokawa, P.H. Kim, K. Toyada, S. Namba, K. Gamo, R. Aihara and N. Anazawa: Jpn. J. Appl. Phys. 24 (1985) L566

3) M. Takai, J. Tsuchimoto, H. Nakai, K.Gamo and S. Namba: Jpn. J. Appl. Phys. 23 (1984) L852

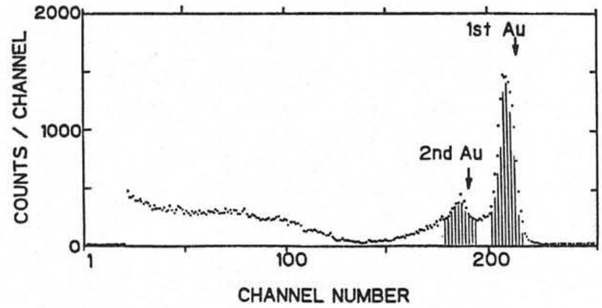
4) P. Bayerl and P. Eichinger: Nucl. Instr. and Meth. 149 (1978) 663

5) H. Kneis, B. Martin, R. Nobiling, B. Povh and K.Traxel: Nucl. Instr. and Meth. 197 (1982) 79

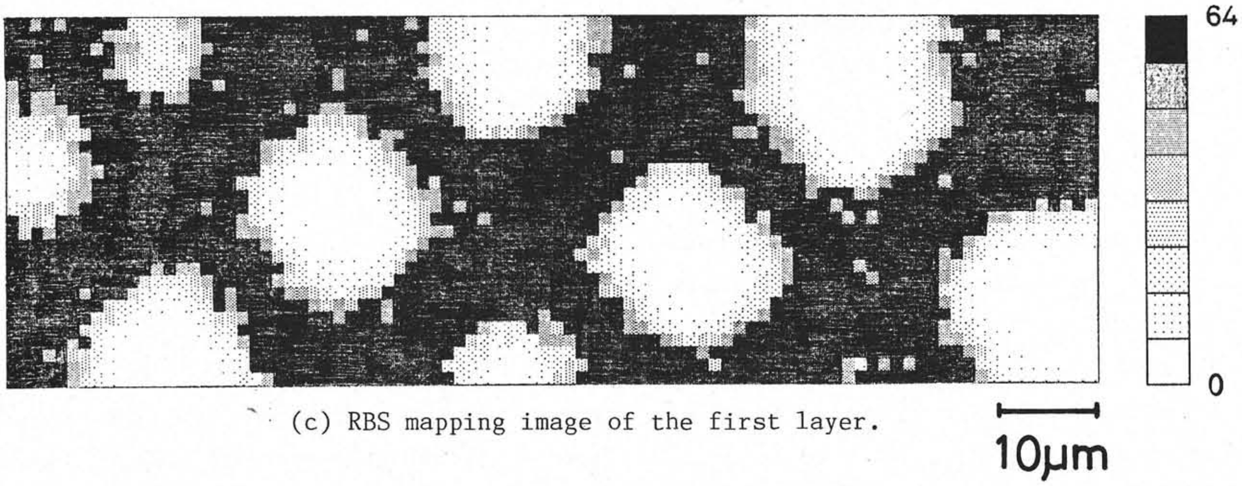
6) M. Takai, K. Matsunaga, K. Inoue, M. Izumi, K. Gamo, M. Sato and S. Namba: Jpn. J. Appl. Phys. 26 (1987) L550



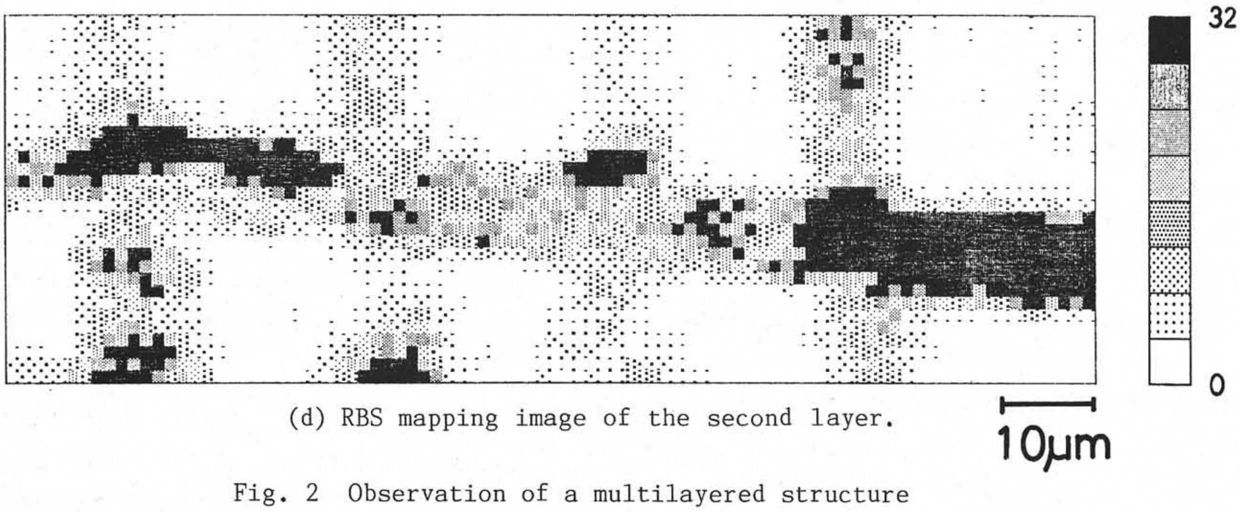
(a) Schematic diagram of the substrate.



(b) RBS spectra with a defocused beam.



(c) RBS mapping image of the first layer.



(d) RBS mapping image of the second layer.

Fig. 2 Observation of a multilayered structure consisting of two gold lattices isolated with silicon dioxide.