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The Uji Scanning Proton Microprobe

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Abstract

The Uji scanning microprobe system has been developed with a simple doublet configuration. The beam size was reduced to 18×16 μm with current of the order of 100 pA. The optical parameters have been calculated for comparison.

Introduction

Scanning microbeam PIXE and RBS have been accepted as powerful tools for the spatial elemental distribution analysis for their high sensitivities. Developments on the Uji proton microprobe started in 1985 and have been described in the publications[1,2]. In the previous paper[2], we reported on the two doublets configuration of quadrupole lenses. It was, however, quite difficult to adjust four quadrupoles independently to get sufficient focussing. Thus, in the present experiment we adopted a simple doublet configuration to investigate the beam properties systematically. For this purpose several improvements have been made in experimental arrangement and in data analysis. The optical parameters have been calculated including the chromatic and third order aberrations for comparison.

Experimental

The experimental set-up of the Uji scanning microprobe apparatus in its present form is shown in figure 1. As several experimental improvements have been made since the previous report[2], we present a brief description in the following.

The copper single hole specimen meshes for an electron microscope are used as the object apertures. These object apertures ranging from 10 to 1000 μm in diameter are assembled in an aperture holder. By sliding the aperture holder one can change the object aperture size easily. The crossed slits placed just before the object apertures collimates the main portion of the beam to prevent the damage of the aperture disk against beam heating. The collimator slits are placed 92 cm apart downstream from the object to control the divergence of the beam entering the first Q-lens and to remove the scattered beam from the object aperture edge.

In the previous arrangement, the deflection electrodes were placed between the last Q-lens and the target. Two dimensional wide scanning of MeV proton beam required electrodes of several tens centimeter long. In the present arrangement, therefore, the deflector is replaced between the collimator slits and the first Q-lens. A pair of deflection electrodes were added for the sake of wide area scanning on referring to the Oxford microprobe[3]. Negative high voltage amplifiers are added to prevent the beam distor-

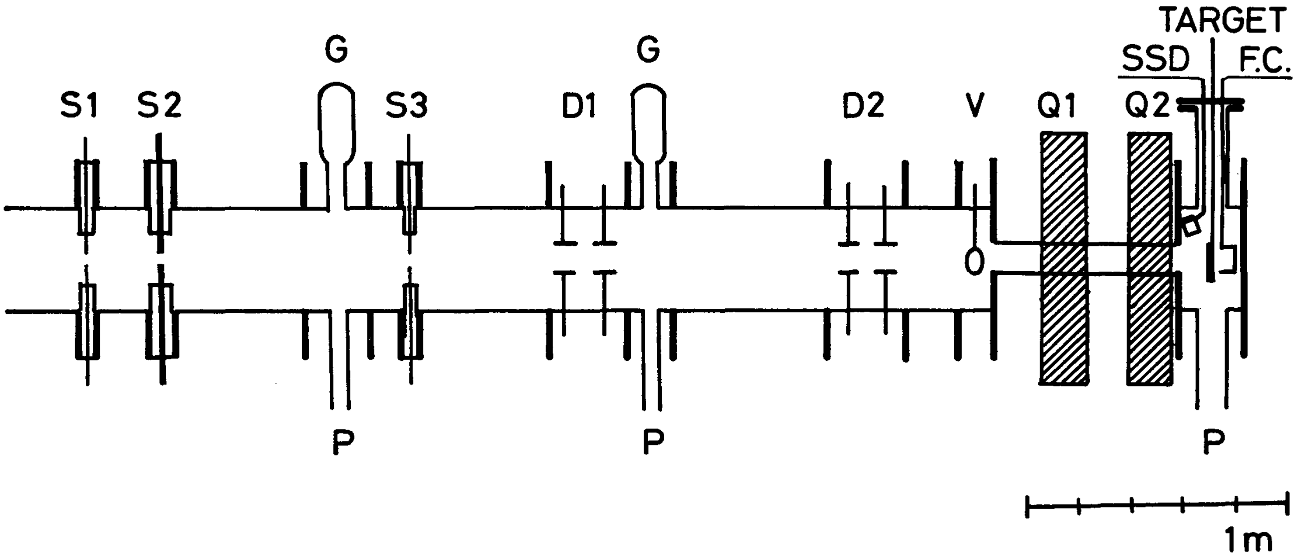

Fig. 1. The experimental arrangement of the Uji scanning microprobe. (S 1: crossed slits, S 2: object aperture, S 3: collimator slits, D 1 and D 2: deflector, Q 1 and Q 2: quadrupoles, F.C.: Faraday cup, SSD: detector, V: viewer, G: vacuum gauge, P: 2″ oil diffusion pump)

tion in the deflector.

A microcomputer is used for controlling the beam scanning and for data acquisition. Electronics has been described in the previous paper[2]. A part of the computer program for on-line data display has been revised with machine language. By this change, dead time during the data acquisition decreased to about one milisecond per channel in MCS mode. Fast repeatable scanning became feasible and the influence of the fluctuation of the beam intensity decreased remarkably.

A removable Faraday cup is inserted just behind the target to monitor the beam currents. The collected charges by the Faraday cup and the target are fed to the beam current integrator. The dwell time at each points in the raster is determined by either the output pulse of the current integrator or the clock pulse from 100 Hz timer. Scanning by integrated beam currents were also performed preventing the influence of the fluctuation of the beam intensity.

Beam transport duct is evacuated by three 2″ oil diffusion pumps. As the beam passes about 6 meters before entering the first quadrupoles, it is indispensable to keep the pressure of the transport duct of the order of 10^{-6} Torr. Otherwise considerable parts of the beam change their charge states which degrades the property of the microbeam significantly.

Results

In the present experiment, 2 MeV proton beams from 4 MV van de Graaff accelerator at Uji were used. Focussing of the microbeam was carried out by the following steps. First, initial focussing was achieved down to several tens micrometer by viewing the beam spot on a thin glass plate mounted at the target position. The light spot size was observed with a microscope placed after the target position. An object aperture which has four holes at each corner of the square was prepared to facilitate this procedure. Second, final focussing was carried out by observing the RBS spectra of scattered protons from a 150 lines/inch copper electron microscope grid.

In figures 2 and 3 are shown the RBS spectra scanned across a 250 lines/inch copper grid in both the vertical and horizontal directions and in figure 4 is shown the result of two dimensional scan. The object aperture of 50 μm in diameter was used.

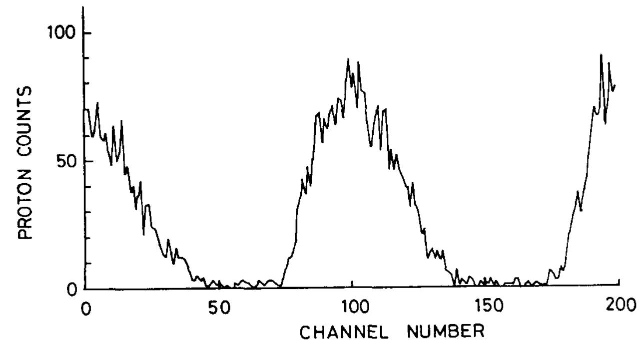

Fig. 2. RBS scan of a 250 lines/inch electron microscope grid in vertical direction.

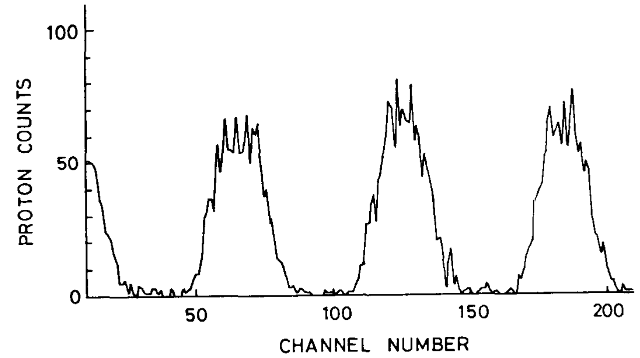

Fig. 3. RBS scan of a 250 lines/inch electron microscope grid in horizontal direction.

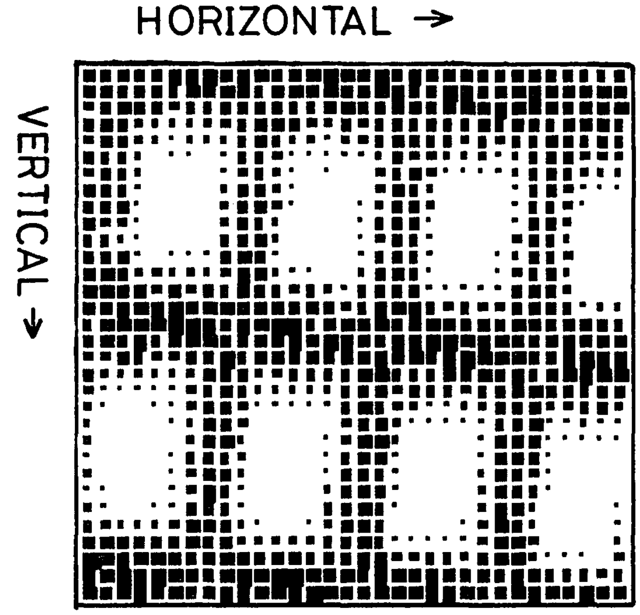

Fig. 4. Two dimensional image of RBS scan of a 250 lines/inch copper electron microscope grid. The grid lines are 40 μm in width and the repeat distance is 102 μm.

The grid lines were measured by using an optical microscope to be 40 μm in width and the repeat distance 102 μm. The displacement per channel was calibrated dividing the grid repeat distance by repeat channel width calculated from the autocorreltion function of the observed spectrum.

When the beam width is comparable or larger than the grid width, the beam witdth is simply evaluated by subtracting the grid width from the measured FWHM. In the present experiment, the beam width for each direction was calculated by least squares fitting. Figures 5 and 6 show computer fits to one complete cycle obtained from the vertical and horizontal scans of the grid assuming a Gaussian beam profile and rectangular cross section for the grid. Deconvolution calculations show that the beam spot dimension of 18 ± 4 μm and 16 ± 4 μm for vertical and horizontal plane, respectively.

Discussion

When a focussed beam size is not so small, the first order calculation gives adequate description for the beam optics. Such calculation based on a simple matrix formalism[4] has been described in our previous paper[2]. With decreasing the beam size, the knowledge of chromatic and third order spherical aberration are required. The important optical parameters are the magnifications (x/x_0) and (y/y_0), the two main chromatic aberration coefficients $(x/\theta\delta)$ and $(y/\phi\delta)$ and the four third order spherical aberration coefficients (x/θ^3), (y/ϕ^3), $(x/\theta\phi^2)$ and $(y/\phi\theta^2)$. These aberrations in the Gaussian image plane are given by

$$x_i = (x/x_0)x_0 + (x/\theta\delta)\theta\delta + (x/\theta^3)\theta^3 + (x/\theta\phi^2)\theta\phi^2$$

and

$$y_i = (y/y_0)y_0 + (y/\phi\delta)\phi\delta + (y/\phi^3)\phi^3 + (y/\phi\theta^2)\phi\theta^2$$

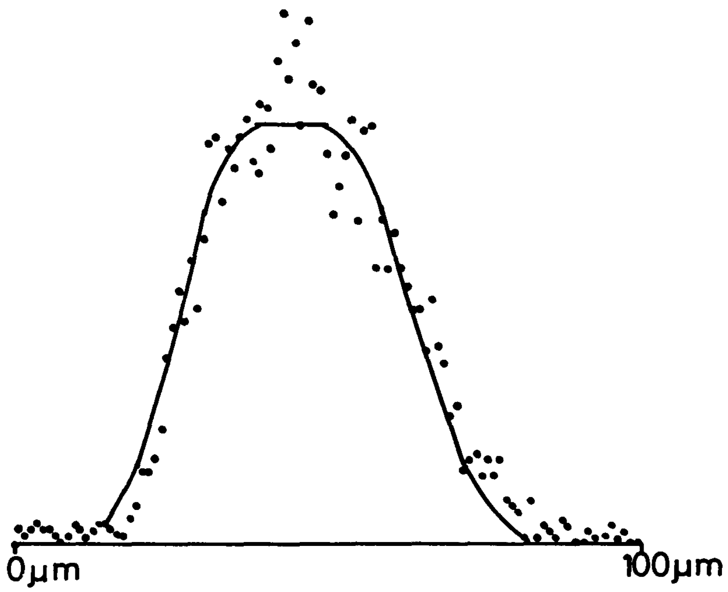

Fig. 5. Computer fit to the RBS profile (vertical).

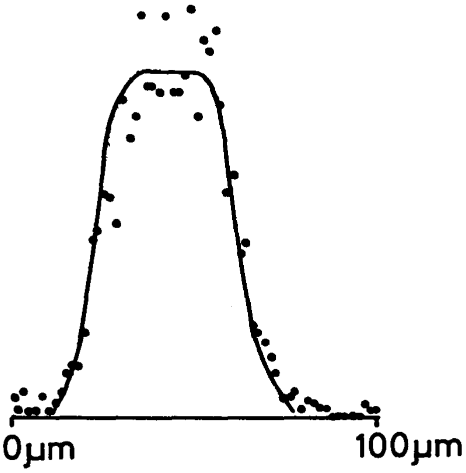

Fig. 6. Computer fit to the RBS profile (horizontal).

Table 1. Beam optical parameters of doublet configurations

	Demagnification factors		Spherical aberration coefficients				Major Chromatic aberration coeffs.	
	$(x/x_0)^{-1}$	$(y/y_0)^{-1}$	(x/θ^3)	(y/ϕ^3)	$(x/\theta\phi^2)$	$(y/\phi\theta^2)$	$(x/\theta\delta)$	$(y/\phi\delta)$
Uji	−2.8	−21	−0.8	−4.7	−7.0	−0.9	7630	8428
Heidelberg	−25	−4.5	−5	−1	1.6	−8	3700	3900

All spatial and angular dimensions in μm or miliradians.

where θ and ϕ are the divergences of the beam at the object aperture in the x and y-plane respectively, x_0 and y_0 are the object aperture size and δ is the fractional momentum spread of the beam. These beam optical parameters of the doublet under investigation have been calculated using computer program ORBIT[5]. The results are listed in table 1 together with the relevant parameters of Heidelberg doublet[6] which have been calculated by Oxford group[7].

In the present experiment, the beam divergences were estimated to be less than 50 microradians in the vertical and horizontal plane, respectively. And the energy spread of the proton beam is estimated to be 1 part to 10^3. From the calculated parameters, it is concluded that the third order spherical aberrations are negligible and the major aberration effect comes from the chromatic ones. In the present arrangement, a large demagnification in y-plane was canceled by a large chromatic aberration. The measured beam size agreed very well with the calculated one. According to the calculated parameters, the beam size of about three micormeters can be attained by replacing the object aperture of 10 μm in diameter and controling the beam divergences less than 10 microradians in both planes.

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