Focused Ion Beam System and Maskless Microfabrication

Susumu Namba

The Institute of Physical and Chemical Research, (RIKEN)

Ion implantation, so far, has been done using uniform ion beams and selective doping has been performed using patterned masks. If intense and fine focused beams are available, no patterning process is necessary and doping at desired areas can be done by a vector scanning of ion beams. In addition to such maskless ion implantation, fine focused beams have many potential applications in maskless sputter etching, and microprobe analysis[1,2] such as scanning ion microscopy and secondary ion mass spectroscopy.

There has been an increasing interest in liquid metal ion (LMI) sources because it has a high source brightness and can be used to produce intense fine focused beams[3,4]. Up to now various metal field ion sources have been built[5-7], but these are limited to elements which have relatively low melting points and low vapor pressure at melting points and which wet emitter tips without any significant reaction.

For various applications, many important elements such as B and As have high melting points or high vapor presuure. For these elements, eutectic alloys can be used[8,9]. B, for example, has a melting point highter than 2000°C, but B-Pt eutectic alloys which include 40 weight percent of B has a melting point of 800°C and so a low temperature operation can be expected. Desired ions can be separated by using a mass separator.

An example of a LMI source is shown in Fig. 1. The source is composed of an emitter tip, a metal reservoir and an extraction electrode. The emitter tip is made of tungsten with a diameter of 300μμm and electrochemically polished to form a conically shaped point with a typical cone half angle and radius of 17° and 0.5 μm respectivily. The extraction electrode is put 0.5 mm apart from the emitter tip.

The ionization mechanism of a LMI source is not fully understood but it is believed that a field evaporation and a field ionization is most probable ionization process[4)].

An example of a mass spectra of LMI sources using a liquid metal alloy is shown in Fig. 2 for As alloy sources[10)]. The alloys used are As_{28} Pt_{72} and has a melting point of 597°C. For LMI sources, intense doubly charged ion is often observed as As^{++} and Pt^{++}. Doubly-charged ion beams are useful for high energy implantation because the beam energy are twice of the acceleration voltage. For As^{++} beam, an angular current intensily of 4 μA/sr is obtained at a beam energy spread of 10 eV.

A fine focused ion beam can be formed using a electrostatic lens system. Many fine focused ion beam systems have already been built using LMI sources. Figure 3 shows a block diagram of a focused ion beam system which use two symmetric einzel lens and a E x B mass separator, and Fig. 4 shows a photograph of the focused system[10)]. The column length between the source and the target is 535 mm. A secondary electron detector is set at the target chamber to observe a secondary electron image.

Figure 4 shows the calculated beam spot size as a function of the beam acceptance half angle. In the calculation, the source size and an energy spread (FWHM) of an ion beam is assumed to 30 nm and 10 eV, respectively.

The EXB mass separator distorts a beam spot and induce an elliptical spot due to the energy spread of the beam. The dotted line shows a calculated length of the major axis for a beam energy of 70 keV. In the calculation, we assumed that the mass resolution $\Delta m/m$ is 0.1, that is, ^{10}B and ^{11}B can be separated. It is clear from Fig. 4 that a desired ion beam can be obtained with negligible distortion by using a liquid metal alloy source and an EXB filter. For the present system, 70 keV As^{++} beams with a diameter of 0.3 μm and a current of 100 pA can be formed.

Figure 5 shows an example of secondary electron images of 50 μm Cu mesh observed by the present mass-separated focusing system. The probe ions are Au^+ ions accelerated at 50 KeV. The resolution obtained is 0.5 um.

The process using focused ion beam is not only simple but also reliable and controllable because in-situ monitoring is easily be performed.

Figure 6 shows an example of a hole in a Si_3N_4 membrane formed by sputtering using 50 keV Au^+ beam. These structures were formed to fabricate Josephson microbridges. The process can be monitored by measuring a current at a sample holder as shown here. At an initial stage, all Au^+ ions are stopped in Si_3N_4 film and no current is detected at the sample holder. When a hole is formed, a sharp rise of the current is observed because Au^+ ions reach the sample holder through the openning in the Si_3N_4

membrane.

Maskless direct ion implantation and FET fabrication have also been investigated[3] and potential importance of focused ion beam has clearly demonstrated.

1) R. Levi-Setti: "Scanning Electron Microscopy/1974" Vol. 1 Proc. 7th Ann. SEM Symp. (Chicago, 1974) p.125

2) J. Orloff and L.W. Swanson: "Scanning Elecrtron Microscopy/1977" Vol. 1, Proc. 10th Ann. SEM Symp. (Chicago, 1977) p.57

3) R.L. Seliger, R.L. Kubena and V. Wang: Jpu. J. Appl. Phys. 21 (1982) Suppl. 21-1, 3

4) R. Gomer: Appl. Phys. 19 (1979) 365

5) L.W. Swanson, G.A. Schwind and A.E. bell: "Scanning Electron Microscopy/1979" Vol. 1, (SEM Inc., 1979) p.45

6) R. Clampitt and D.K. Jefferies: Nucl. Inst. Methods 149 (1978) 739

7) A. Wagner and T.M. Hall: J. Vac. Sci. Technol. 16 (1979) 1871

8) K. Gamo, T. Ukegawa and S. Namba: Jpn. J. Appl. Phys. Lett. (to be published)

9) K. Gamo, T. Ukegawa, Y. Inomoto, Y. Ochiai and S. Namba: J. Vac. Sci. Technol. 19 (1981) 1182

10) K. Gamo, Y. Inomoto, Y. Ochiai and S. Namba: Proc. 10th Intern. Conf. on Electron and Ion Beam Science and Technolozy (Montreal, 1982) (to be published)

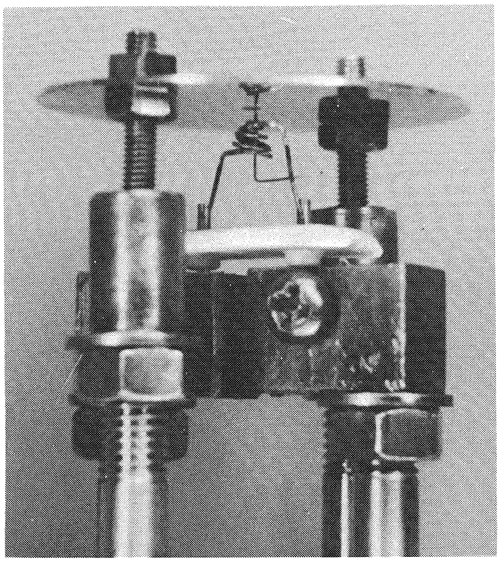


Fig. 1 Liquid metal ion source

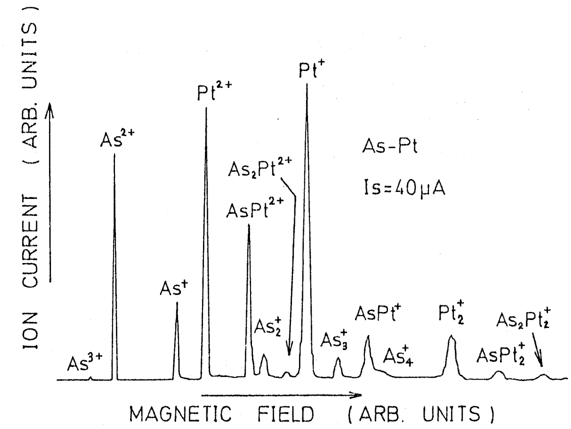


Fig. 2 A mass spectra for As alloy ion sources

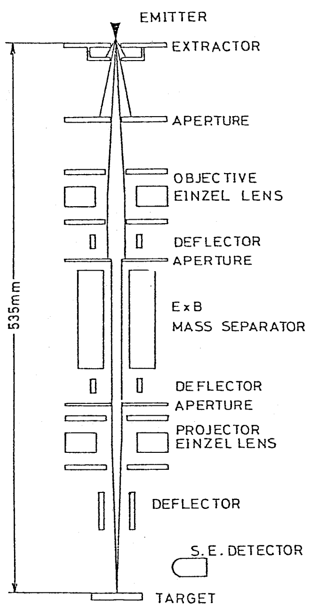


Fig. 3 Focused ion beam system

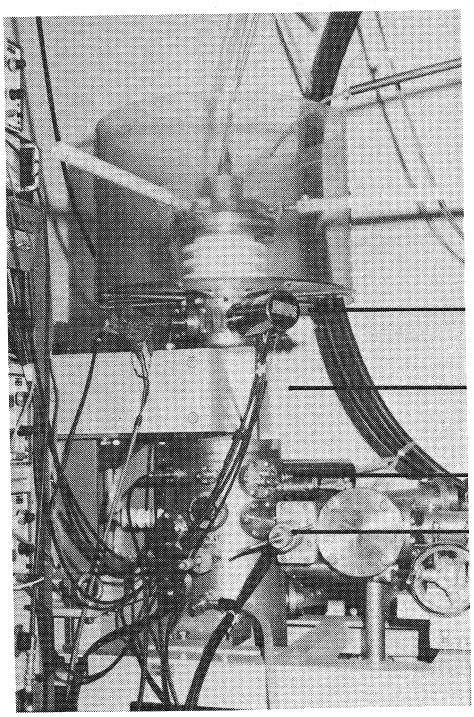


Fig. 4 Photograph of a focused ion beam system

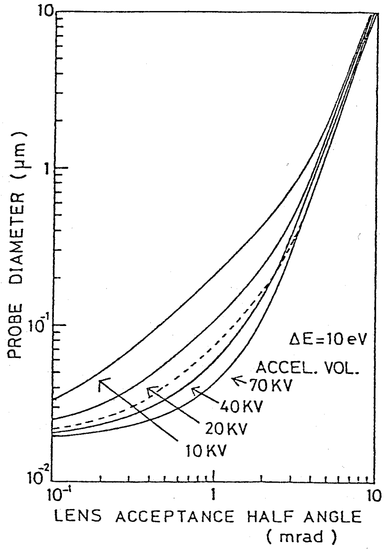


Fig. 5 Probe diameter as a function of a lens acceptance half angle

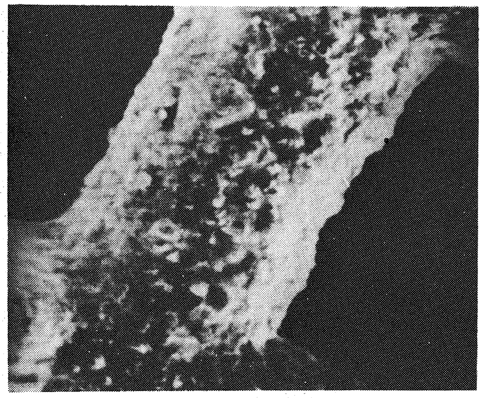
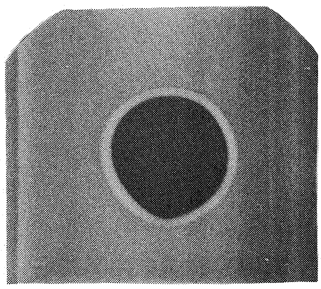


Fig. 6 Secondary electron image of a Cu mesh observed by 50 keV Au^+



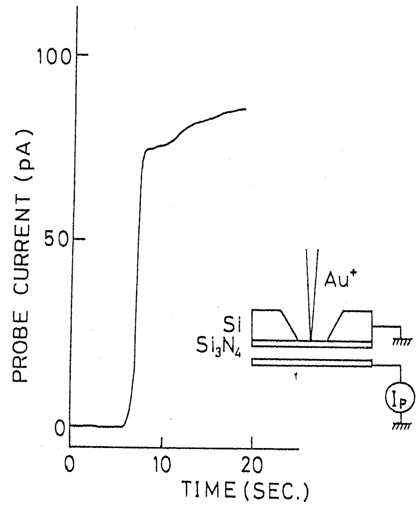


Fig. 7 A pinhole in Si_3N_4 membrane formed by focused ion beam and probe current as a function of time