THE POSSIBILITY OF THE ION BEAM MACHINING OF THE HIGH TEMPERATURE SUPERCONDUCTOR Bi2223

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Abstract

In this paper, while the previous examination result about minute machining of a Bi2223 thick film is described, the details of the possibility of ion beam machining and a beam irradiation system and an actual irradiation experiment plan are presented.

INTRODUCTION

In recent years, it is progressing that development of the equipment to which high temperature superconductivity technology has been applied in the field of an accelerator. For example, the application to the beam current monitor in a beam transport system [1], ion beam storage ring, etc. is known. Although Bi_2-Sr_2-Ca_2-Cu_3-Ox (Bi-2223) etc. has been used as a high temperature superconductor in these equipments, since the high temperature superconductor Bi2223 coated on a substrate is various as a basic material of superconductivity electronics, attention is attracted. When applying this basic material to an electronics circuit, circuit patterning with resolution of sub μm and multi-layered structure of the material are demanded. The current minute patterning technologies such as a focused ion beam (FIB) irradiation is applied to deposit an only mono-layered metal (ex Niobium) on the substrate for making low temperature superconductivity electronics. Although the printing method is investigated about circuit patterning of Bi2223, this method can be patterned only in the stage of printing which is one stage of the creation process of a superconductor, and minute pattern machining is made difficult from restrictions of heat contraction in the stage of calcinations etc. For this reason, it requests for development of the machining method in which minimizing is possible.

This paper examined how to etch the pattern required for the thick film of Bi2223 to the MgO substrate at uniform thickness like a copper-plated print circuit board. In order to form arbitrary patterns, it examined first whether the technique of wet etching adopted by the semiconductor manufacturing process and dry etching would be inapplicable. Since the chemistry substance as etchant needed to be specified about wet etching, research which directed its attention to the etching rate of Bi2223 film was performed. Consequently, although the good result was obtained and it was promising about wet etching, it turns out that contamination of the basis material by etchant and the load to environment are large.

So we had started the study of ion beam machining of Bi2223 in the various ion energy ranges from 1 KeV to 100 keV.

ION BEAM ETCHING

The plasma etching method and the ion beam etching method were examined for dry etching. It decided for plasma and the ion species of an ion beam to adopt the Ar with many papers about the reaction with the substance etched. About the plasma method, dry etching by commercial ion-sputter was considered. The most promising method is a method of setting a sample to the negative electrode of sputter, applying the Ar plasma of pressure 0.02 Torr, and etching the surface. Figure 1 shows calculated sputtering process of 10 keV Ar^+ ions in Cu.

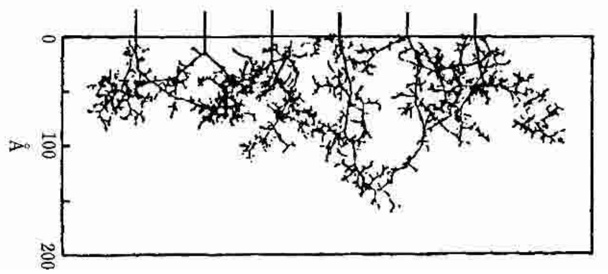

Fig. 1. Calculated sputtering process of 10 keV Ar^+ ions in Cu. [From F. Fujimoto, K. Komaki Ion Beam Technology, (1995) 240]

It planned choosing the beam from the Hi ECR ion source installed in the CNS about etching the sample by the Ar ion beam, setting a sample to the focal plane of beam focusing equipment, and performing an irradiation experiment. Ion current density enabled it, as for the irradiation size of a beam, for this plan to realize 100μA /cm^2 by 10mm diameter. Moreover, the degree of vacuum of the vacuum chamber for irradiation was designed so that 10^{-8} Torr might be obtained. The introductory mechanism of reactive gas is also examined so that ion beam etching may be performed early, and the kind of reactive gas was also examined to apply a reactive ion-beam etching (RIBE). Since an irradiation sample was an oxide, it was examined also about the difference in each etching rate of a composition element (Bi, Sr, Ca, Cu, O). Although multi-charge ion is taken out, deceleration electrode is installed in the irradiation system, and it enabled it to change the energy in this ion source. Moreover, in order to perform comparison with the Ar ion beam of single charge, the test by the commercial ion beam milling equipment for SEM (Scanning Electron Microscope) sample creation is planned.

ION SOURCE

We considered the Hi ECR ion source for ion beam machining. The Hi ECR has been constructed at CNS to study the optimum parameters for producing multi-charged ions comparable to 14 GHz operations by using 10 GHz microwave source. The effort on experimental study has been concentrated to how support gas, microwave frequency and the mirror coils field contribute to the production of multi-charged ions in ECR zone.

Table 1. Parameters of Hi ECR.

Mirror field	
Side of gas-feed	8 kG
Side of extraction	7 kG
Hexapole magnet	
Field on plasma chamber	10.4 kG
Inner diameter	76 mm
Mechanical length	145 mm
Microwave power source	
Frequency	10 GHz
Input power	88 W
Plasma chamber	
Inner diameter	70 mm
Ion species (typ)	Ar^{q+} $q \leq 9$

The Hi ECR comprises nine solenoid coils (Mirror coils), a hexapole magnet (Halbach-type), a high frequency RF feeder and a plasma chamber. To produce multi-charged ions, we need high electron density. Therefore electrons are confined by magnetic field generated by the mirror coils. The parameters of Hi ECR are tabulated in Table 1. In order to analyse charge-mass ratio *e/m* of ion beam, an analysing magnet with bending angle of 90-degree and a Faraday cup were set downstream of the Hi ECR. Producing ions with Ar gas only carried out the beam experiment of Hi ECR operated at 10 GHz. During the operation, the mass flow rate of Ar gas was adjusted to maintain the pressure to 2×10^{-6} Torr.

BEAM TRANSPORT LINE

We have constructed a beam transport line for a Hi ECR ion source with a 10 GHz power source. The beam transport line comprises an analyser magnet (BM) as mentioned above and $Q_FQ_DQ_F$ magnets (QTM). The specifications of all the magnets are tabulated in the published paper [2]. Table 2 shows the beam diagnostics instruments. There are three sets of vacuum pumping system as shown in Table 3. We have designed the beam optics associate with making a parallel beam at the end of beam line. The lattice structure and result of calculation are shown in Fig. 2. A DC beam current monitor is installed in the end of beam line. The assumed beam emittances are the same to 200 πmmmrad in the vertical and the horizontal planes. In calculation of beam envelopes, full-width of beam momentum spread is calculated as 0%.

It is easy to make a focusing point at the exit of BM, which is followed by the beam diagnostic devices. A beam slit and Faraday-cup 1 (FC1) are put on an image focal point of the BM. Ion species with selection of the charge to mass ratio has been carried out with the slit and FC1. A wire monitor [3] can measure the beam profiles in x-y directions. A screen monitor is also available to observe the beam profile using a TV camera.

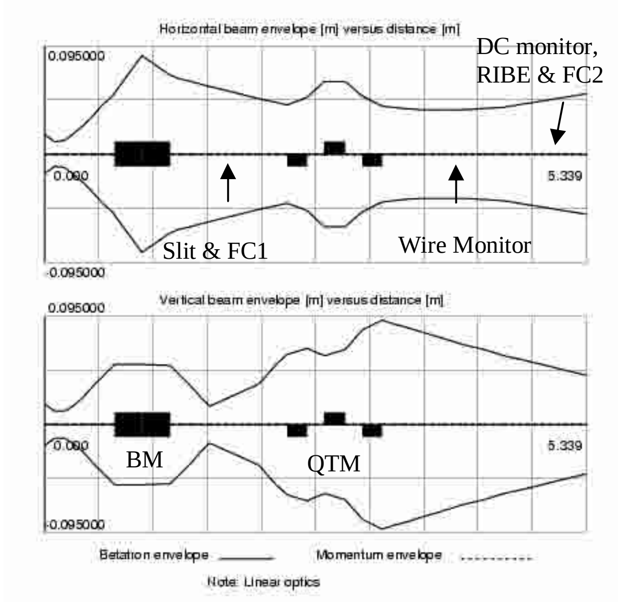

Fig. 2. Beam envelopes of the Hi ECR ion source beam transport line. The beam is guided from the left to the right. The RIBE instruments are placed at the end point of beam line.

Table 2. Beam diagnostic instruments

Slit and Faraday cup 1	Cu, Slit =10 mm max.
Tungsten wire monitor	100 μm, Au coating
Screen monitor	71x50 mm^2, 95%Al_2O_3+Cr
DC beam current monitor	HTS-SQUID sensor type
Faraday cup 2	SUS304, 100 ϕ L=0.5 m

Table 3. Vacuum pumping system

Hi ECR IS chamber	500 L/s TMP+RP
Analyzer magnet chamber	300 L/s TMP+RP
Beam monitor chamber	250 L/s TMP+RP

In order to confirm the beam optics we made a measurement of Ar^{3+} beam at an extraction voltage of 10 kV. The slit width is chosen to 10 mm. The measured beam widths (FWHM) are 9.5 mm in horizontal and 17 mm in vertical, respectively. The beam current of 1.8 eμA was measured with DC beam current monitor and was confirmed with the Faraday-cup 2 (FC2). We confirmed that analysing power of the BM and beam optics of the whole system is a good for testing the Hi ECR ion source.

REACTION CHAMBER

A reaction chamber was considered in order to irradiate the beam on the high temperature superconductor Bi2223. This equipment consists of a beam guide, gate valve, deceleration electrode, deflection electrode, vacuum pump, sample holder, Faraday cup, etc. In order to act as the monitor of the intensity of irradiation current on-line, the DC-SQUID monitor is installed in front of the reaction chamber. The reactive-gas spraying equipment and the introductory equipment for promoting the etching rate on the surface of the sample in the reaction chamber again attach gas recovery instrument outside. A test stand of the reaction chamber is shown in Fig.3. The planed reaction chamber with designed vacuum pressure of 10^{-8} Torr is attained by the 500 L/s TMP system.

Fig. 3. Test stand of the reaction chamber.

XeF_2 as a neutral gas and a toxic gas Cl_2 were already examined elsewhere about reaction gas. In Si, only in the case of an Ar^+ ion beam, XeF_2 has an etching rate remarkably early at a part for 70 Å/min compared with a part for 8 Å/min in the case of only Ar^+ ion beam [4]. Although Cl_2 is toxic gas, it resembles markedly a part for increase etching yield with increase of potential energy. The plan was carried out using 10 kV Ar^{q+} ions at pressure of ~$1x10^{-5}$ Torr of Cl_2, since enforcement improves the etching yield of Gallium-Arsenide (GaAs) at high potential energy ($q \geq 7$) [5]. We will follow those results in order to etch the thick film of Bi2223. For comparison, the typical examples of etching rate for Ar ions with normal incident angle are tabulated in Table 4 [6]. These etching rates are obtained at operating conditions of ion energy 1.0 keV, current density of 1.0 mA/cm^2, and pressure of target chamber is 5×10^{-5} Torr.

The reaction rate of a mask for preventing the ion beam bombardment plays a role to make minutes of pattern of Bi2223. The ratio of etching rates of the mask and Bi2223 is to be considered from 5 to 10 because of large aspect ratio. The mask for the reactive ion beam etching is being developed for various ion beam lithography. For examples, PMM electron-resist provides etching rate of 840 Å/min and AZ1350 photo-resist shows etching rate of 600 Å/min as shown in Table 4. The advanced ion-beam resist such as PMMA (Poly (methyl methacrylate)) could be applicable in the ion beam lithography as shown in Fig. 4 [7] in order to obtain large aspect ratio.

We will try to apply these resists to make a good solution for minute ion beam machining of the high temperature super conducting materials*.

Table 4. Etching rates (Ar ions at normal incident angle)

Target	Å/min	Target	Å/min
Silicon	360	Aluminum	444
GaAs	2600	Zirconium	320
SiO2	420	Niobium	300
Fe oxide	660	Iron	320
Gold	1600	Chromium	200
Silver	2000	Aluminum	130
PMM e-resist	840	AZ1350 photo resist	660

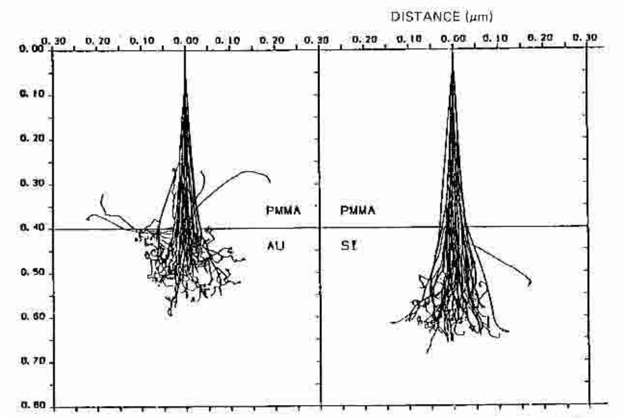

Fig. 4. Trajectories of 60 keV H^+ ions in PMMA on substrates of gold and silicon calculated by PIBER program. [From L. Karapiperis, *et al. J. Vac. Sci. Tecnol*. 19, (1981) 1260]

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