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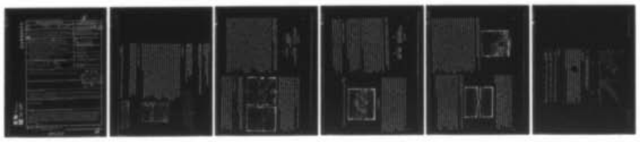

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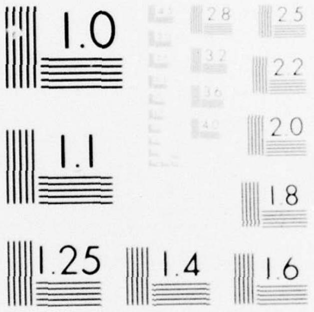

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Techniques have been developed for the fabrication of variable thickness constriction (VTC) microbridges. The bridges produced by these techniques display the superior characteristics found by others in VTC bridges made by scratching techniques. The EBL techniques described have the advantage of being easily applicable to fabrication of large arrays of nearly identical bridges.

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PREPARATION OF VARIABLE THICKNESS MICROBRIDGES USING ELECTRON BEAM LITHOGRAPHY AND ION ETCHING[**]

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I INTRODUCTION

We have developed techniques using electron beam lithography (EBL) and ion beam etching to fabricate indium Josephson microbridges. For the past several years we have been making the usual uniform thickness bridges using EBL.[1] These bridges are formed by constricting a single 100 nm thick film in one dimension. Typical dimensions of the bridges are 0.3μm square, however bridges as small as 0.2μm square have been made. More recently we have been making bridges of the variable thickness geometry in which the film is constricted in two dimensions, i.e. thickness as well as width. Variable thickness bridges (VTB) have been constructed by locally thinning a single thick indium film by ion beam etching and by a two step evaporation process in which a thin narrow strip which forms the bridge is overlayed with a thick film forming the banks of the bridge. The latter process is much more reliable in producing repeatable bridges with well defined geometry; however, it was found necessary to use an intermediate step in which the first film is cleaned with an ion beam prior to the deposition of the second film in order to insure good superconducting contact between the film.

II ELECTRON BEAM LITHOGRAPHY

We briefly review the techniques of electron beam lithography,[2] Fig. 1. Saphire substrates are spin-coated with a positive electron resist, poly methyl methacrylate (PMM). The resist is baked and coated with a

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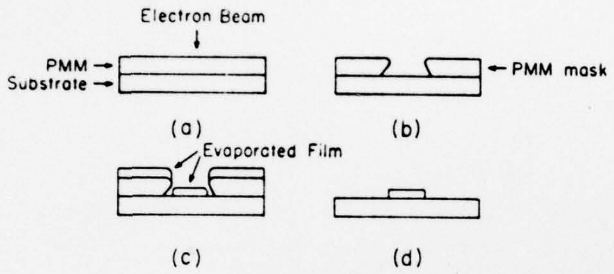
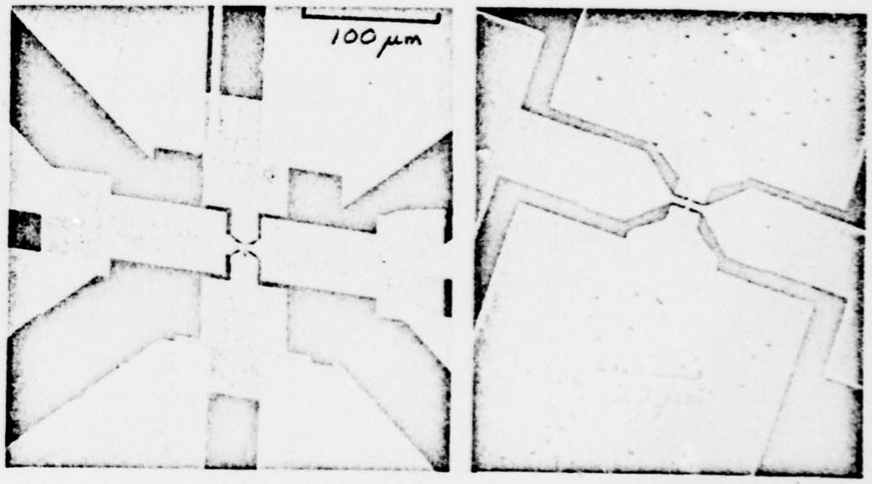


Fig. 1. EBL process. a) Substrate spin-coated with PMM and exposed to electron beam. b) Developed PMM. c) PMM mask with evaporated film. d) Final pattern after lift off.

thin layer (≈ 7.5nm) of Al to prevent charging during the exposure to the electron beam. The sample is then exposed by a 10nm diameter electron beam from a scanning electron microscope. The position, blanking and exposure time of the electron beam are computer controlled. The field is divided into a matrix of points and the pattern is written on the PMM by moving the beam to the desired points under computer control. Between points the beam is blanked and the time the beam is unblanked on each point is also controlled by the computer. Complex patterns are thus written by simple user written software. After exposure the Al is removed and the resist is developed in a dilute solvent. The effect of exposure to the electron beam is to break the molecular bonds of the PMM. Thus after development the PMM is removed in the areas which were exposed by the electron beam. Because of the scattering of the electrons from the substrate and the PMM during exposure, the mask also exhibits a significant amount of undercutting. This scattering also causes the exposure rate of an area to be dependent on the exposure of adjacent areas. It is often necessary to increase the exposure time of small regions such as the bridge relative to other regions. Next a thin film is evaporated through this mask. Because of the undercutting there is a break between the film on the substrate and on the mask so that when the unwanted film is now removed by dissolving the mask in acetone, the film lifts off cleanly without tearing.

While the undercutting is desirable it does limit the resolution of the technique when thick films and thus thick resist layers are used since the undercutting becomes more severe as the resist is made thicker. The computer controlled electron beam technique however allows one to fabricate repeatable complex submicron sized patterns such as arrays of microbridges. Fig. 2 shows a sample used to study the voltage locking and coupling interactions of two microbridges.[3]



(a) (b)

Fig. 2. Two microbridge series array made by EBL. a) Micrograph showing eight gold terminals to indium film. b) Micrograph of indium film containing two microbridges spaced ≈ 1μm apart.

III. ION BEAM ETCHING

In the ion beam etching process a indium thin film is first deposited on the substrate, then a mask usually made by EBL is placed on top of the film. The entire sample is then exposed to a 1 kV argon ion beam. The portion of the In film not protected by the mask is then selectively removed, Fig. 3. For some applications the PMM mask itself may be used

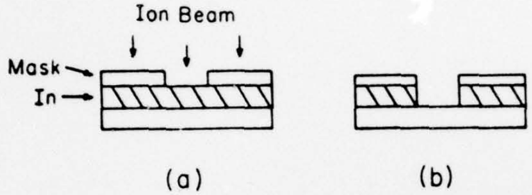


Fig. 3. Ion beam etching. a) Entire In film and mask exposed to ion beam. b) In film removed in region not protected by the mask.

as the mask for ion etching. PMM however etches rapidly and nonuniformly and after etching times of more than a few minutes polymerizes and is impossible to subsequently remove. For most applications we have found that Al film masks made by the EBL lift-off process to be very effective Then Al etches very uniformly and when etched in a oxygen environment (usually just the residual oxygen in the vacuum system) the etching rate approaches that of Al oxide which is very slow <10nm/min, about 7-8 times slower than indium. Because of the slow etch rate of Al relative to In, thin high resolution PMM masks may be used to construct the thin ≈ 30nm Al masks used in etching 200nm In films.

Another interesting masking method we have found is the use of the organic contamination produced by the electron beam of the scanning electron microscope. After an exposure of the sample to the electron beam of $\approx 10^{-7}$ coul/$(\mu m)^2$, a contamination layer builds up which is nearly impervious to the ion beam. The resolution of this mask is only limited by the resolution of the electron microscope.

IV. PREPARATION OF MICROBRIDGES

One of our first attempts to make variable thickness bridges was to thin a single thick In film (≈ 200nm) in a localized region by partially etching with the ion beam through an Al mask. Unfortunately In does not etch uniformly as shown in Fig. 4. Upon further etching several

crystalite bridges are formed between the banks as shown in Fig. 5. It is possible to produce a single microbridge by additional masking with either Al or contamination and save one bridge while removing the others with further etching. While this is not a reliable method of producing repeatable microbridges, bridges made by this method do exhibit the Josephson effects. From Fig. 5 however, it is clear that when the etching process is allowed to continue until all the In has been removed, the Al masking techniques is effective in fabricating structures with nearly vertical edges with an edge definition less than 0.1μm. We are pursuing techniques using Al and contamination masking to make uniform thickness bridges of dimensions smaller than is presently possible with PMM masks.

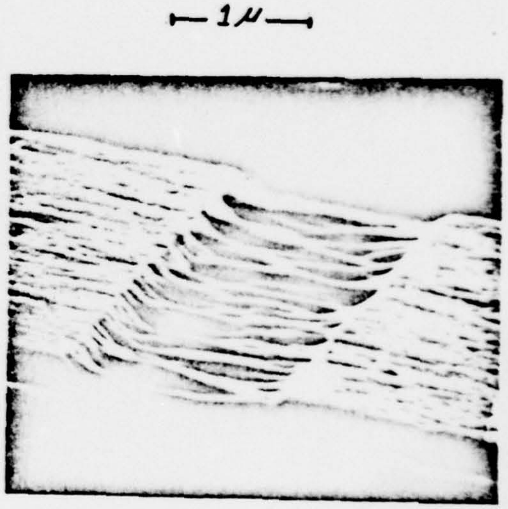


Fig. 4. Micrograph showing nonuniform etching of In film through Al mask.

Fig. 5. *Micrograph of ion etched In film and* Al mask in which all In is removed in the gap except two crystallite bridges.

A more successful method of making VTB which yields bridges with well defined geometry and allows the systematic variation of the length, width and to some degree the thickness of the bridges is a two step process. First a thin 50nm, narrow (< 0.5μm) In strip which will form the bridge is deposited by EBL. Next a second PMM mask with a gap less than 0.5μm wide is constructed across this strip. A thick In film (200-300 nm) deposited through this mask then forms the banks and electrodes for the microbridge. Fig. 6. However before the second film is deposited it is essential that the first film be briefly etched by the ion beam to remove any oxide and contaminates and insure good superconducting contact between the films. In fact we found it necessary to perform the evaporation of the second film immediately after etching without exposing the sample to atmosphere. Earlier attempts in making bridges by this two step process in which the sample was briefly exposed to atmosphere in the process of transferring it from the etching to the evaporation chamber yielded bridges which exhibited the Josephson effect but had normal state resistances of several ohms and properties more characteristic of tunnel junctions. We therefore modified the equipment such that after deposition of the first film and construction of the second PMM mask the sample

is placed in a vacuum chamber and pumped to less than 10^{-6} Torr. The film is then etched by a 1.3 kV,0.75 ma/cm^2 argon beam for 15 sec. at 10^{-4} Torr. The system is then pumped to 2×10^{-7} Torr and the sample rotated onto a liquid nitrogen cooled stage and the thick In film is evaporated through the mask. Bridges produced by this method have characteristics nearly identical to those produced by thinning a single film described above, indicated that good contact is made between the two films.

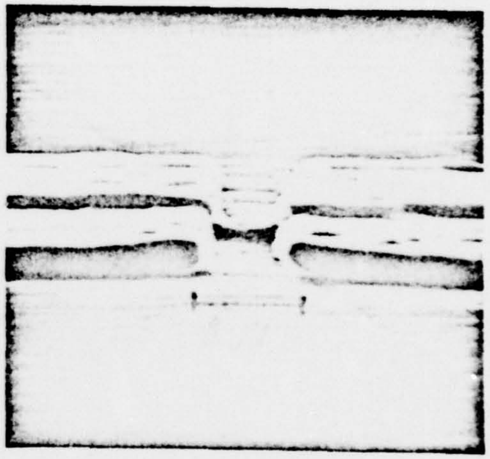
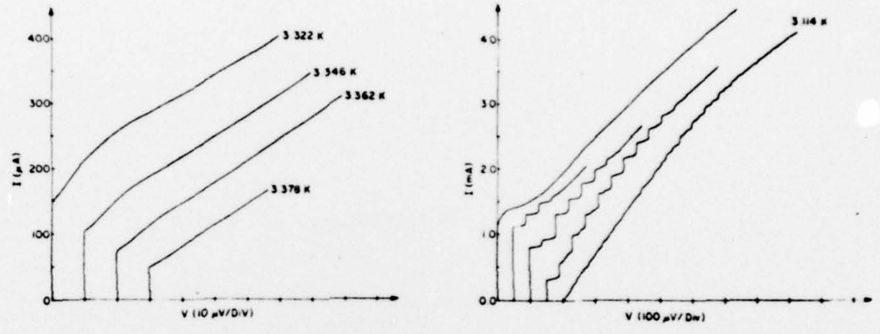


Fig. 6. Variable thickness bridge with film thickness of 250 and 50 nm made by the two step process.

The microbridges ≈ 0.5μm square and 50 nm thick have normal state resistance of 0.1 - 0.3 ohm. Typical current voltage characteristics are shown in Fig. 7a. At lower temperatures the characteristics deviate from the RSJ model as evidenced by the region of negative curvature. At lower temperatures the I-V curves become hysteric when the critical current reaches 1.5 - 2.0 mA, however the hysterisis occurs first not at zero voltages but in the region of negative curvature. The response of a bridge to 19.3 GHz radiation is shown in Fig. 7b. Microwave induced steps have been observed at 1mV and are observed in general up to and just beyond the gap voltage 2 Δ/e.



(a) (b)

Fig. 7. a) Current-voltage characteristics of a VTB.
b) Response of VTB to 19.3 GHz radiation.

V. CONCLUSIONS

The versatile electron beam lithography and ion beam etching techniques allow the reliable fabrication of uniform and variable thickness Josephson microbridges. [illegible] advantage of these techniques is the ability to systematically vary [illegible] dimensions of the bridge. We are currently investigating the characteristics of both types of microbridges such as intrinsic noise, current-phase relations, and coupling interactions of a two junction series array.

REFERENCES

1. D.W. Jillie, J. Lukens and Y.H. Kao, IEEE Trans. Mag. MAG 11 (1975) 671.
2. I. Haller, M. Hatzakis and R. Srinivasan, IBM J. Res. and Dev. 12 (1968) 251.
3. D.W. Jillie, J.E. Lukens, Y.H. Kao and G.J. Dolan, Phys. Letters 55A (1976) 381.