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NATIONAL RADIO ASTRONOMY OBSERVATORY
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M E M O R A N D U M

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Subject: SIS Junction Fabrication Facilities in the U.S.

I attended the 1994 Applied Superconductivity Conference which was held in Boston, MA on October 16-21, 1994. My objective for attending this conference was to have discussions with researchers from EVERY SIS junction fabrication group still existing in the U.S., including a review of their fabrication process, an assessment of their fabrication capabilities and discovering whether any of them would be interested in and capable of making devices for the MMA.

In addition to UVA, there are eight groups which make $Nb/Al_2O_3/Nb$ junctions in the U.S. Below is a brief summary of their current status and my personal observations and comments. *Since this memo contains some sensitive information, I would appreciate having it kept confidential.*

CURRENT STATUS

1) Conductus - Dr. Stephen Whiteley

Conductus is now mainly focused on high T_c superconducting electronics work (*e.g.*, HTS filters for the cellular phone industry). The in-house low T_c work has been reduced to a very low level. In fact, according to Steve, they are now buying Nb devices from Hypres for their own low T_c applications.

2) Westinghouse - Dr. Arthur Davidson and Dr. A. Hodge Worsham

The primary interest of the Cryogenic Electronics Group at Westinghouse is the development of HTS components for company RADAR work. It also has a Nb junction fabrication facility. Typical current density is 1000A/cm^2 and minimum junction size ~ 3.5 μm. They cannot do Nb anodization and are not interested in altering their fabrication process (*e.g.*, increasing j_C and reducing the junction size) to meet the MMA's requirements.

3) Cryoelectronic Metrology Group, NIST - Dr. Richard Harris

The main interests of this group are to develop and maintain Josephson junction voltage standards and to perform other related superconductivity research. I visited this group four years ago. Based on my discussions with Dick at that time, I am fairly certain this group is not interested in providing foundry service to the community and I did not discuss our needs with them.

4) Prof. Van Duzer's group at UC/Berkeley - Dr. X. F. Meng

The facility is primarily used for student training and some HTS projects. They do not have the capability to make devices for the MMA.

5) Hypres - Dr. Elie Track and Dr. Masoud Radparvar

Hypres still provides Nb foundry service to the superconductive electronics community. The standard design rules (rev. 12) are: (1) j_C from 100 to 5000A/cm^2, (2) junction size ~ 3 μm, (3) no anodization step, (4) use 3" quartz substrate, and (5) ~ $30k per run. Hypres is very interested in making devices for the MMA and is willing to modify its process to suit our needs. Since NRAO has had a very good and successful collaboration experience with Hypres before (all our 3mm SIS receivers currently operating on the 12-m telescope still use Hypres junctions), we shouldn't have any problems working with them. However, I was told that, following the most recent shake-up at Hypres, it now has only three fabrication staff left and the quality of Hypres devices has deteriorated accordingly. Recently UVA also reported that the trilayer wafers they got from Hypres showed very poor anodization characteristics. I think we should carefully re-examine Hypres' capabilities before we consider collaborating with them again.

6) Consortium For Superconducting Electronics (CSE) - Dr. Manjul Bhushan (SUNY/SB) and Ron Miller (AT&T)

CSE was formed five years ago. Participants of CSE are IBM, AT&T Bell Lab, Lincoln Lab, and SUNY/Stony Brook. Among these four, Lincoln Lab does not have the capability to make junctions. IBM is cutting back their superconductivity research effort. In fact, the biggest news at ASC was the announcement that IBM licensed all its superconductivity patents and all superconducting know-how developed at its Thomas J. Watson Research Center to a company called Quantum Magnetics. IBM still maintains a small group working on low-noise SQUID's, but most of our contacts at IBM have either already left (A. Davidson is currently at Westinghouse) or planning to leave (A. Kleinsasser will join JPL in January 1995). The chance of getting devices from IBM is very slim. Manjul Bhushan at SUNY/Stony Brook can make excellent high current density, small area junctions (*e.g.*, 0.003 μm^2 junction with j_C ~ 2,000A/cm^2 and 0.006 μm^2 junction with j_C ~ 330,000A/cm^2) using trilayers provided by Ron Miller of AT&T Bell Lab. We had already talked to Ron and Manjul about the possibility of getting devices from Stony Brook/Bell Lab and received encouraging responses from both of them. However, since both have their own full-time commitments (Ron supplies Nb wafers for all AT&T's internal projects and Manjul needs to provide devices for Luken's Josephson junction oscillator work and Likhrev's Rapid Single Flux quantum (RSFQ) project), they may not be able to provide the kind of extensive support we need for the MMA.

7) TRW - Dr. Hugo Chan and Dr. Lynn Abelson

There is a Nb foundry service at TRW. It is a twelve-level process setup mainly for digital applications. Typical design parameters are: (1) junction size = 2.5 μm, (2) j_C ~ 2,000 A/cm^2, (3) use 4,000 Å SiO_2 as insulation layer, (4) thickness of Nb wiring layer ~ 5,000 Å, (5) use 4" substrate (it can be either Si or 20 mils-thick quartz), (6) no anodization step, and (7) j_C varies less than 5% across the entire 4" wafer. Price for three complete wafers is $50k, which includes the costs for the masks. Lynn said that since we will need, at most, 7 layers for our devices, TRW may be able to make devices for us at a substantially lower cost. My main concerns are: (1) j_C is too low for high frequency mixer application, and (2) we may have problems in thinning the 20 mils-thick quartz substrates during the mixer assembly process. On the other hand, a large size (4") wafer means that we can get a lot more low frequency mixers from each run, provided that we could properly thin the substrate after the devices were made. This is something worthy of exploring.

8) JPL's Nanodevies and Superconductive Electronics Group - Dr. Rick LeDuc, Dr. Jeff Stern and Dr. Bruce Bumble

Like UVA, the main goal of this group is to develop superconducting mixers and detectors for radio astronomy applications. Typical device parameters are: (1) j_C ~4,500 - 20,000A/cm^2, (2) can make sub-micron size junctions, (3) no anodization step, (4) use 2,500 Å SiO as insulation layer but can add another 3,000 Å SiO if needed, (5) thickness of Nb wiring layer ~ 2000 Å, and (6) use 4 mil-thick 1" dia. quartz substrate. According to Rick, cost/overhead is about $180k/man-year at JPL (this is roughly the same as what they charged in SMA's $500,000 three-year contract). The JPL process was primary developed for submillimeter applications (*i.e.*, single junction or two-junction array, high j_C and sub-micron junction size). We could ask them to modify their process to suit our special needs (*e.g.*, add an anodization step), but, the high cost of the service may be prohibitive. They are very interested in collaborating with us to provide devices for the MMA, but I can also tell that they are uneasy about what Tom Phillip might say about this kind of collaboration. Apparently, there were at least two occasions when Tom instructed them NOT to provide devices to certain groups. It seems to me that unless we can get Tom's blessing, any collaboration with JPL will be a very rocky one.

MMA REQUIREMENTS AND JUNCTION FABRICATION COST

According to the MMA proposal, there will be at least 320 SIS receivers in the MMA (4 bands x 2 polarizations x 40 antennas). Recently, there have been discussions regarding the use of image separation receivers on the MMA. An image separation receiver with high LO coupling efficiency can be constructed by using a pair of balanced mixers. Since the most basic design of balanced mixer consists of two single-ended mixers, the total number of SIS mixers required by the MMA would be at least 1,280. (This would be one of the largest REAL superconducting electronics projects ever carried out since Josephson discovered his famous superconducting tunneling effect in 1962!) Recent advancements in the SIS mixer technologies have demonstrated that such a project can be done provided that *at least one good and reliable Nb SIS junction fabrication factory can be located in the U.S.* Among the eight groups mentioned in this memo, Hypres, TRW and JPL have expressed interest in making SIS mixers for the MMA. However, in order to meet the MMA's requirements, each of these groups will need to modify and fine-tune their standard process (*e.g.*, add an anodization step), a tremendous and time-consuming process. Hypres and JPL may also need to increase their fabrication staff to handle the extensive work MMA demands.

It is difficult to estimate the MMA SIS junction fabrication cost at this moment. However, since (1) the MMA may need ~ 21 times (1280/60) more SIS mixers than the SMA does and (2) based on the information I got from Rick ($180k/man-year) and the SMA - JPL contract ($500k/3-year), one might infer that the cost of the junctions could be as much as $10M if we purchase them from JPL. Since both TRW and Hypres are commercial foundrys, their costs will be at least at the same level as JPL's.

SITUATION AT UVA

Having assessed the capabilities of these eight groups, I would also like to examine NRAO's collaboration with UVA's superconducting device group. NRAO helped establish this group in 1986 and since then has maintained a very close working relationship with them. Although this group NEVER received enough funding support from NRAO and other funding agencies to reach the critical mass needed to thrive in the current research environment, they did manage to produce some record-breaking devices for us in the past. Since the main goal of the UVA group is to make SIS mixers for NRAO and other radio astronomy groups, their fabrication processes are specially developed to meet the MMA's requirements. Also, compared to JPL, TRW and Hypres, the fabrication cost at UVA is substantially lower. In my opinion, the UVA superconducting device group has the capability to produce SIS devices for the MMA and may well be the only place from which we can afford to get devices. However, there are real concerns regarding the health of this group. For instance, the lack of funding and full-time high level experienced staff has severely hampered their efficiency and capabilities to the point that they have been unable to produce any useful devices in the past 18 months. Although, at this moment this crisis seems close to being over (UVA just delivered two wafers with excellent test junction I-V characteristics to us), unless they can get substantially

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MORE funding support from NRAO or other sources, similar crises are bound to happen again and again.

SOME THOUGHTS AND RECOMMENDATIONS

Although making good junctions is no longer a process involving black magic, it will still take any of the groups mentioned above several years to fine-tune their process and build up their production capacity to meet the MMA's enormous demand. In my opinion, the most efficient and economical approach for NRAO to take at this time is to substantially increase its support to UVA so that they can add at least one more full-time, experienced Ph.D.-level fabrication staff member and have enough development and equipment money ($200k/year?) to refine and maintain their fabrication process and to boost their production capacity. One should also realize that, since the junction fabrication processes are very complicated, occasional failures in producing these devices are unavoidable and some time may be required to resolve the problems (similar situations occur on commercial semiconductor production lines all the time). In order to ensure a timely supply of SIS devices for the MMA, it is desirable to have a SECOND (BACK-UP) junction supplier. I think either JPL, Hypres, or TRW should be able to provide this service.