MANDRELS FOR ELECTROFORMED SUPERCONDUCTING CAVITIES FOR THE INTERNATIONAL LINEAR COLLIDER

PERSONNEL AND INSTITUTION REQUESTING FUNDING

Institution: Cornell University, College of Engineering and College of Arts & Sciences

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COLLABORATORS

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All of the above have senior academic appointments at Cornell.

Cornell NanoScale Facility (CNF) Staff
Cornell Center for Materials Research (CCMR) Facilities staff.

PROJECT LEADER

Prof. Lou Hand of the Cornell Physics Department and CCMR will be the project leader. Email: lnh1@cornell.edu, or hand@ccmr.cornell.edu. Tel:(607) 255-6023.

PROJECT OVERVIEW

Goals of this research:

The purpose of this proposal is to create a suitable mandrel for electroforming niobium cavities for superconducting accelerators, specifically the ILC. A satisfactory mandrel will have the following properties:

- It will reproduce the desired cavity dimensions on the micron level or better. The mandrel must therefore be mechanically stable for 100 hours at 800^{o}C.
- The mandrel surface on which the niobium will be deposited will be highly polished with very low roughness—less than 35 nanometers rms. The surface defect density will be low.
- It will be scratch and dust free.
- The mandrel can be immersed in a molten salt mixture such as KCl, CsCl, NaCl, NaF and K_2NbF_7 at temperatures of 760-800^{o}C. The immersion time will be up to 100 hours at this temperature. Diffusion into the niobium of the mandrel metal (Ni, or Cu) must be less than one micron.
- The mandrel must be removed without damaging the niobium cavity surface. For example, copper and nickel can be removed by dissolving in ferric chloride. Surface contamination of the niobium from the molten salt immersion and the mandrel removal must be limited to one micron or less.

- Mandrels must be able to be constructed at sufficiently low cost (in a mass production mode). A mandrel for a full size nine-cell 1.3 GHz multicell ILC cavity should not exceed $1000 (2006 dollars) each in a production run of 21,000 such mandrels.
- The mandrel will be constructed of either nickel or copper. The purpose of our research is to determine whether one of these satisfies the criteria above, and to construct mandrels for a half-scale 2.9 GHz electroformed test cavity prototype. Copper is the preferred choice to start with.

Discussion:

The Cornell NanoScale Facility will give technical support to this proposal. At this Facility, electroplated copper can be put on almost any surface, with an outer surface roughness that depends only on the chemistry, and not on the surface it goes onto. (Assuming a minimal degree of substrate smoothness). 5 nm rms roughness can be achieved. This roughness will be transferred to the niobium surface when molten salt niobium electrodeposition takes place onto the copper mandrel. A major activity of the proposed research will be to check that this is in fact true, by using flat coupons of copper on which niobium is electrodeposited after first checking the surface quality of the copper itself, then dissolving the copper and measuring the rms roughness of the niobium surface.

We can also test whether it will be necessary to add a few nanometers of a buffer film on the copper before immersing it in the molten salt mixture used for niobium electrodeposition. The necessity and composition of this buffer film, which will probably be transferred to the niobium cavity inner surface will be determined. One choice could be 1-5 nm of aluminum oxide, which will also prevent format of the natural oxide of the niobium when it is exposed to air. Our cavity tests can determine if this affects the operation of the cavity more than the native oxide does now in cavities constructed by conventional methods. Still another buffer film, feasible at the CNF, is electroplating a few nm of gold. This gold can be removed in the finished niobium cavity with a KI etch.

The copper mandrel is electroplated on a substrate of plastic that can be injection-molded to high dimensional precision and reproducibility. Techniques to do this at low cost are well developed in industry. There are local companies in the Ithaca area specializing in prototypes of this kind, and other local companies that design the molds for the injection molding process. We feel confident that low-cost mass production of precision plastic substrates for the copper mandrels will be possible using these standard techniques.

The plastic substrate must be safely removed from the copper mandrel before it can be used in the niobium electroforming process. This can be done in a benign way by using supercritical carbon dioxide to selectively dissolve the polymer from the copper. This is very similar to the process used to selectively dissolve caffeine to make decaffeinated coffee beans, and is therefore well known. If a small amount of cosolvent is used in the supercritical fluid, a wide variety of polymers can be dissolved, including low molecular weight polystyrene and poly(methyl methacrylate) which are two excellent candidates for the plastic substrate. Supercritical carbon dioxide is the solvent of choice since it is nonpolar and will not harm the metal layer.

The remaining problem to be solved is how to be certain that the outer dimensions of the copper mandrel (which form the inner dimensions of the niobium cavity) are exactly correct and are reproducible. This is a metrology problem of great importance to this project. We will experiment in the CNF with various ways of ensuring that the mandrel has the correct shape and dimensions. One way is careful control of the electroplating timing, current density and chemistry. Again, we benefit directly from the technical support of the CNF.

The mandrel must be self-supporting and not deform at 800^{o}C in the molten salt bath. With copper, this could be a problem. Nickel, with a much higher melting temperature, and greater strength, can also be electroplated, but we would have to experiment with obtaining a less than 35 nm surface roughness, since, in the CNF, nickel electroplating has not previously been done. There are no obvious barriers to doing this, in the opinion of the experts, but experience with electroplating nickel is lacking, and the chemicals would have to be purchased. We prefer starting with copper. Diffusion of the mandrel metal into the niobium will not be a problem at 800^oC. For nickel this is calculated for 100 hours to be 100 nanometers, and for copper, much less. (Equilibrium solubility of nickel in niobium is 7% and of copper is 8% at this temperature. We do not expect the paramagnetism of nickel to be a problem either, since this top 0.1 micron of the surface will have to be removed, if necessary, by a small degree of chemical etching or electropolishing.) Grain boundary diffusion can be much more than one calculates from diffusion constants. If that is the case then the diffusion barrier of aluminum oxide, gold or perhaps tantalum nitride will prevent it. More coupon experiments will then be needed.

BROADER IMPACT

In the Executive Summary of the 2005 Augustine Report to the National Academy, it was suggested that the US leadership in high energy physics should be restored, as a national priority. The ILC addresses this by having the US be a significant part of a world collaboration: Europe, the Americas, and Asia. Such an unprecedented collaboration would help to create a positive image of the US, besides opening an important scientific frontier in particle physics.

Cornell has a policy of diversity in all its activities, and, of course, this policy will be followed by this grant, if it is awarded.

RESULTS OF PRIOR RESEARCH

Professor Lou Hand has been a member of CCMR for seven years. During that time, five papers were contributed to three SRF Workshops (the last one being 2005) on the various properties of niobium films. Since 2002, Prof. Hand has been engaged in finding ways to lower the mass production cost of SRF cavities without sacrificing quality. In practice, this means an accelerating gradient above 50 MV/m, and a high field quality factor Q above 10^{10} at 1.8^oK.

In 2002, a SGER NSF Grant was awarded to Prof. Hand (Award # 0226076, DMI Division, 9/01/2002-2/29/2004). With this grant we attempted to make cavities by physical vapor deposition of niobium, on a graphite mandrel, with a cavity shell constructed of plasma-sprayed tungsten copper alloy. This project was unsuccessful, and has been abandoned. The grant proposed here is an entirely different approach, which is based on bulk niobium, not film-based cavities.

FACILTIES, EQUIPMENT AND OTHER RESOURCES

The facilities of CNF and CCMR are too numerous to list here. Please see the web site urls given here.

CCMR is an NSF-sponsored MRSEC. To find a description of the CCMR facilities, see the web address: http://www.ccmr.cornell.edu/facilities. Of particular interest to the proposed project is the Surface Facility (see url above plus /surface/) and the Ion Beam Analytical Facility (see above url plus /ion/.

The Cornell NanoScale Science & Technology Facility (CNF) is sponsored by NSF, Cornell University, New York State Office of Science, Technology and Academic Research, industry and & users. The facilities are described on the web site url: http://www.cnf.cornell.edu.
(See above plus /cnf_processes.html/).

PROGRESS REPORT

This is a new proposal. It is intended to do basic materials science research in coordination with a response to a DOE solicitation for SBIR Phase I proposals submitted Dec. 2 by Plasma Pros, Inc. of

Huntsville, Alabama, who propose electroforming of superconducting accelerator cavities. L.N. Hand has agreed to consult on this SBIR proposal. *However, this University-based research proposal is independent of the SBIR Phase I proposal.* Even if that DOE Phase I SBIR is not funded or is not successful, the work proposed here will produce suitable mandrels for potential electroformed cavities.

FY2006 PROJECT ACTIVITIES AND DELIVERABLES

Activities will concentrate on deposition of a suitable substrate for electroforming mandrels. The mandrels will be deposited on a plastic substrate, which is then removed, leaving a free standing mandrel. The emphasis will be on obtaining a mandrel surface that will allow elimination, after the electroforming of, most of the current extensive surface treatments of niobium in superconducting cavities. Nickel and copper will be considered and evaluated as candidates for mandrel materials. The criteria will be smoothness (rms roughness will be the criterion), plus a low contamination of the electroformed niobium surface during the electroforming and the mandrel removal.
Milestones will be:

1. Coupon studies of mandrel roughness and niobium contamination by the mandrel at the operating temperatures of the electroplating.
2. Coating of suitable plastics to a self-supporting (at 800^{o}C) thickness of copper or nickel.
3. Possible diffusion barriers if needed.

FY2006 PROJECT ACTIVITIES AND DELIVERABLES

It is intended to complete the mandrel research in a period of one year, which is the duration of the proposed funding. In conjunction with the SBIR, if Phase I is funded, we will supply the mandrel for a 2.9 GHz model of a reentrant ILC single cell cavity to be constructed at Plasma Pros, Inc., who will do the electroforming. In addition, we will help out with the subsequent testing, and report the results of preliminary tests at the next SRF Workshop in 2007.If successful after the first year, we may submit a renewal or new request to the ILC for additional funds.

BUDGET JUSTIFICATION: CORNELL UNIVERSITY

Major funding is provided for technical studies, first on coupons, later on copper or nickel mandrels. This work will be carried out primarily at the Cornell NanoScale Facility (CNF), at CCMR and in Bard Hall, in the Materials Science & Engineering Department, where the SQUID is located.
The equipment item in the budget is an upgrade to the Quantum Design SQUID magnetometer in Prof. van Dover's laboratory. This upgrade (QD MD101B) will permit horizontal axis rotation of electroformed niobium samples in the form of coupons. Better alignment of the sample with the magnetometer magnetic field will permit more accurate determination of the critical fields H_{c1} and H_{c2}, as well as other superconducting materials parameters (like T_c, for example). Although this is more directly related to evaluating the electroformed niobium, it can also be used to determine the effect of trace contamination by the mandrel on the niobium cavity surface, hence the degree of post deposition etching required. (If the SBIR is not approved, we can still do this with CCMR sputtered niobium films). The list price of the MD101B item is $7330. The shortfall of $2172 will be paid from Prof. Lou Hand's personal account at CCMR: M49-3712.
Use of CCMR facilities for electroformed niobium is covered by the SBIR proposal, and is not included in this budget. However, we will need to do tests on mandrel materials (high resolution profilometer measurements, SIMS and RBS using the CCMR facilities), plus contamination studies on the mandrel plus niobium combination (SIMS and XPS on the niobium).
$6000 is budgeted for electroplating coupon experiments and mandrel production for the 2.9 GHz demonstration prototype SRF cavity. These funds will cover the work at CNF. Machining of the

plastic (we will probably not do injection molding in the year covered by this grant) , will be done in the Clark Hall shop of the Physics Department. The Physics Department work will be paid from the CCMR account listed above. This will include materials costs for the plastic substrates.
There is no request for travel funds. We assume that travel to Huntsville will be covered by the SBIR grant. No other travel costs are anticipated. Travel to the next SRF Workshop in 2007 to give a progress report on this work is anticipated, but will be paid privately.

Addendum to Budget Justification: Indirect Costs.

No salaries, wages and fringe benefits are requested. The institutional rate for indirect costs is 58%, which is the MTDC charge for direct costs in this proposal.

ONE-YEAR BUDGET (in then year $)

Institution:Cornell University

Item	FY2006	Total
Total salaries, Wages and Fringe Benefits	0	0
Equipment (SQUID)	5158	5158
Materials and Supplies (CNF)	6000	6000
Xerox, Communications, etc.	1500	1500
TOTAL DIRECT COSTS	12658	12658
INDIRECT COSTS, MTDC X 58%	7342	7342
TOTAL PROJECT COSTS (DIRECT + INDIRECT)	20000	20000