# SUPERCONDUCTING RF ACTIVITIES AT CORNELL UNIVERSITY

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# INTRODUCTION

Development of rf superconductivity for high energy accelerators has been a robust activity at the Cornell Laboratory of Nuclear Studies (LNS) for many years. In order to realize the potential of rf superconductivity, we have always followed a two-pronged approach. On the one hand we selected accelerator applications where the existing state-of-the art of superconducting rf is competitive with alternate technologies, then engaged in a program to design, construct and test suitable superconducting cavities, culminating in a full system test in an operating accelerator. On the second front we have aggressively pursued the discovery and invention of ideas, techniques and materials required to make superconducting rf devices approach the ideal in performance.

Starting with the development of superconducting cavities for high energy electron synchrotrons, we extended the technology to high energy $e^+e^-$ storage rings. In 1975, a 60 cm, S-band superconducting cavity was successfully operated at 4 Mev/m, and Q= $1x10^9$, accelerating a 110 μa beam to 4 Gev in the Cornell Electron synchrotron[1]. In March 1982, we tested in CESR a one meter section of 1500 Mhz muffin-tin cavities equipped with high power fundamental and higher order mode couplers[2]. Upto 12 ma of beam current was held in the storage ring with the superconducting cavity operating at 1.8 Mev/m and an overall Q of $10^9$. Both tests were firsts for high energy electron machines. In Nov. 1984, we conducted our second storage ring beam test in CESR[3], this time using an improved storage ring cavity design, the LE5 elliptical cavity, as well as higher purity Nb material to achieve higher gradients. The better of the two cavities reached 6.5 MeV/m at a resdual Q of $5x10^9$; this is the highest gradient reached in a storage ring test of a superconducting cavity. The cavities were operated successfully in CESR with 22 mA beam current.

The LE5 cavity design has now been adopted for use in the Continuous Electron Beam Accelerator Facility (CEBAF). When completed, this project will be one of the largest applications of SRF technology, using 440 LE5 modules[4]. In the last two years, we have successfully transferred to industry and to CEBAF the cavity design and the technology. Cornell has tested the early industrial prototypes and cavity pairs[5,6,7]. LNS has developed, in collaboration with CEBAF, designs and procedures for cavity pair and cryomodule assembly and testing[8].

Advanced research for future electron accelerators is badly needed if particle physicists hope to expand the energy frontier. Superconducting cavity technology continues to offer attractive opportunities for further advances in achievable voltage at reasonable cost for future accelerators. For Nb, the full potential implies an order of magnitude increase over current capabilities. The SRF research effort at Cornell LNS is devoted to the goal of continuing to improve performance and cost levels to the point that the technology may serve in future TeV scale $e^+e^-$ linear colliders. Towards this end, the principal objective of the continuing program will be to study the causes of limitations on the accelerating fields and quality factors of superconducting cavities. The recent breakthrough discoveries of high $T_c$ superconductors [9] offer a spectacular factor of 3 improvement over Nb in theoretically acheivable accelerating voltage at a factor of 10 increase in operating temperature. Significant R&D will be required to prove whether the intrinsic properties of the new superconductors do indeed offer these expected advantages. If the basic properties are verified, several years of additional R&D will be necessary to exploit these advantages. Realization of these capabilities, however, would make rf superconductivity the leading competitor for collider technology beyond the SSC. Our current program is geared to exploring the high $T_c$ materials and exploiting any superior properties discovered.

## The Second Storage Ring Beam Test in CESR

At the end of 1984, soon after the 2nd Workshop, a two-week beam test was conducted of two five-cell, 1500 Mhz elliptical cavities equipped with fundamental and higher order mode (HOM) couplers[3]. Fig. 1 shows the cavity pair. The thermal conductivity of the cavities was increased by a factor of 3 over that of standard reactor grade Nb using yttrification[10], reaching a RRR ~ 100.

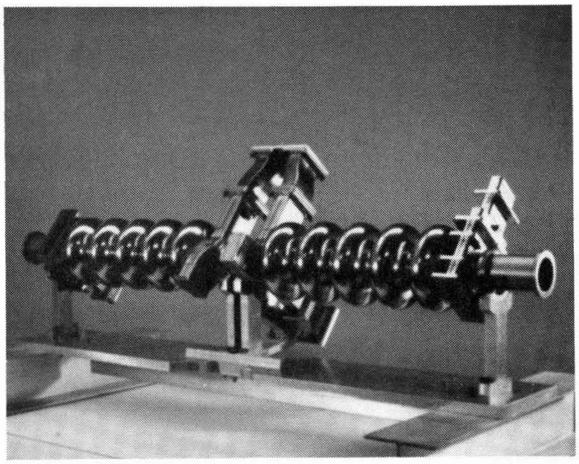

Fig. 1 LE5 elliptical cavities used in the Cornell Electron Storage ring beam test.

The better of the two cavities reached a field of 6.5 MeV/m; this is the first demonstration of the possibility of reaching the 5 Mev/m accelerating gradient which has become the objective of several laboratories. The second cavity reached 2.4 Mev/m; the cause of this limitation has been identified as a dirt spot in the center cell and was removed after the beam test by rinsing with detergent, water and methanol, but no acids. After the rinsing, the cavity reached 11 Mev/m at a Q value of $6x10^9$ and 12 Mev/m at a Q value of $2x10^9$, when substantial field emission loading, but no breakdown was encountered.

The residual Q of both cavities during the beam test was $5x10^9$. The input coupling system delivered 27 Kwatts to the beam without posing a significant cryogenic load. The HOM coupling system extracted beam-induced power with 99.9% efficiency and provided adequate damping to suppress beam instabilities induced by HOMs up to the expected beam current. Over 280 watts of HOM power was generated and successfully extracted. The maximum current with which the cavities were operated was 22 mA (with feedback) and the measured threshold currents for beam instabilities agreed within a factor of 2 with Monte Carlo calculations of multi-turn instabilities in storage rings based on bench measurements and computer calculations of cavity intrinsic impedances and external Q's. This agreement is evidence that that no significant omissions or errors occurred in identifying and determining the properties of the HOMs. The CESR beam test results showed that the Cornell LE5 elliptical cavities are well-suited to a high energy electron storage ring.

Multiturn transverse instabilities involving internal motion of the bunch were a particular concern during the beam test. Computer simulations and analytical estimates of the effect of Landau damping associated with the curvature of the RF potential showed that this damping greatly increased the threshold of the transverse instabilities associated with internal bunch motion, but had negligible effect on those associated with rigid bunch motion. The results of these simulations and calculations were supported by the absence of any transverse internal motion instabilities in the beam test[11].

Substantial effort was devoted to designing and building cryogenic and microwave support equipment necessary for the beam tests in CESR. This includes the main beam line cryostat, cavity tuners operated by stepping motors immersed in liquid He, as well as necessary superconducting waveguide components, microwave windows and heat exchangers for interception of heat flow along input and output waveguides and along the beam line[12]. We installed and operated a 130 Ft liquid He transfer line with pressurized liquid nitrogen, helium pumping systems to lower the bath temperature from 4.2 to 1.8 K, and associated piping and controls. A refrigerator supplying liquid He was operated in closed loop during the tests.

## Assistance to CEBAF

Cornell has interacted closely with four companies (Interatom, Dornier, Babcock & Wilcox and TRW) which were involved in manufacturing LE5 cavities for CEBAF. Five of the cavities manufactured by industry were processed and tested at Cornell[5,6,7]. For these cavities, field values ranged from 6 - 12 Mev/m, (average 8 Mev/m), and the resdual Q's averaged $1x10^{10}$. Two cavity pairs have been assembled and tested (See Fig. 2) A special apparatus for testing cavity pairs has been designed and tested[8]. The pair tests showed performance values comparable to or higher than the individual 5-cell tests. After the pair tests, the cavities are continuously kept under vacuum so that they may eventually be installed in accelerator cryostats without further exposure, and so minimize the difficulty of reliably assembling a string of cavities.

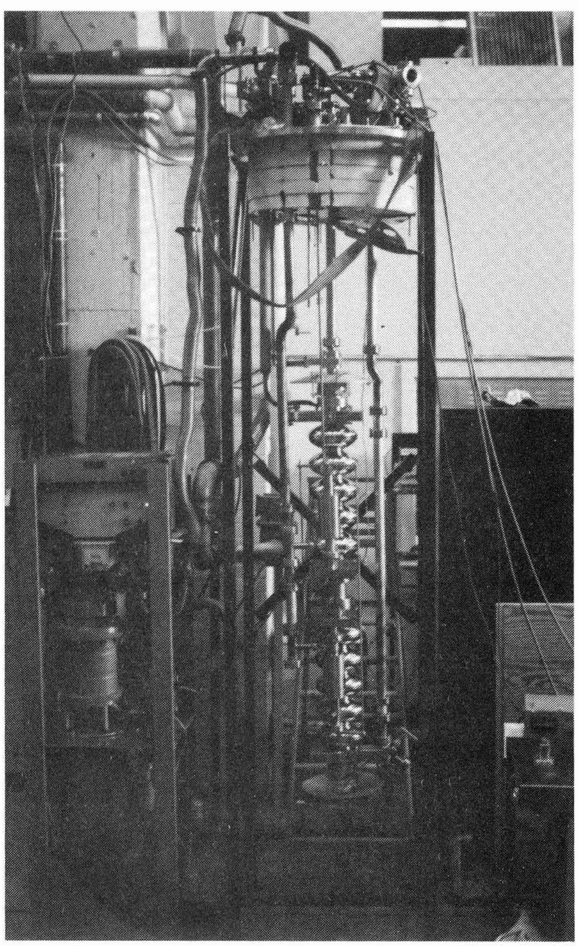

Fig. 2 Pair test for CEBAF.

## RF Superconductivity for TeV $e^+e^-$ Linear Colliders

There is a consensus emerging among particle physicists that the natural complement to a very high energy proton collider (SSC) is a machine that can collide electrons and positrons at a center of mass energy of a few TeV. The conceptual design of such a machine is based on a pair of linacs that accelerate electrons and positrons in opposite directions to an energy on the order of 1 TeV. The very high energy beams are then focussed to a spot with transverse dimensions of a few microns or less and brought into collision. The concept of colliding linacs is an attractive alternative to the storage ring which is not cost effective at energies much beyond 100 GeV. However, a tractable technology for the accelerators capable of very high energy and high repetition rates has not yet emerged.

The costs of a linear collider are associated with the particle sources, physical length, RF power sources, beam power and average operating power. A machine based on state of the art normal conducting technology as realized in the SLC is unacceptably expensive. The capital cost is dominated by the high peak power RF sources and related hardware. In addition the average power required to yield useful luminosity leads to excessive operating costs. The practical realization of a machine based on normal conducting cavities depends on minimizing the beam power by the reduction of number of particles in each bunch, and then the development of very low emittance sources to achieve the high bunch charge densities consistent with high luminosity. The development of accelerating structures and RF sources capable of efficient conversion of energy from wall plug into beam power is required.

A high energy linac based on present-day SRF technology would also be prohibitively expensive. However, if the capabilities of SRF technology continue to advance, such a machine can be built at reasonable cost. The superconducting approach offers real advantages with respect to peak and average power requirements because long rf pulses and multiple bunches can be used. In a superconducting linac the excellent coupling of the energy from the RF source into the beam limits the need for excessive AC power. Because the energy is stored in the accelerating structure with a long dissipation time, the demand for peak power is negligible. The challenge to the superconducting design is to reduce the capital cost of the structure by a combination of higher gradients and economical fabrication.

Technical considerations and costs associated with $e^+e^-$ linear colliders employing superconducting Rf have been explored. Following a study of the capital and power costs of TeV scale cw linacs as a function of performance levels[13], superconducting linacs in which the rf is duty cycle modulated were considered[14]. A cost optimization was performed for a 2 TeV superconducting linac with $10^{33}$ luminosity (cgs units), in which the the rf is operated with a pulsed duty cycle. It is shown that the costs decrease steeply as the gradients approach 30 MeV/m. With Q's of $10^{10}$, and a short duty cycle (1%), capital costs for refrigeration form a small fraction of the overall costs. Using cost coefficients derived from present experience in manufacturing superconducting cavities on the scale of 1 -10 meters, the capital cost of such a machine has been estimated to be close to the estimated SSC capital cost. Further reductions can be expected as the structure costs are lowered.

For application of rf superconductivity to a modulated superconducting linear collider, an S-band rf frequency (3000 Mhz) is judged more suitable than the 1500 Mhz chosen for storage ring and recirculating linac service. As discussed above, in a modulated superconducting linear collider, the rf is turned off after the beam bunches are run through the cavity to allow a substantial savings in operating refrigeration cost.

At frequencies lower than S-band, the cost of dumped stored energy (to room temperature sinks) at the end of each rf pulse increases substantially. At higher frequencies, emittance growth ( $\sim f^4$) during acceleration becomes an important issue.

As a first step in the development of structures suitable for service in a fully superconducting modulated linear collider, we plan to construct and test 3-cell S-band cavities from high purity Nb. To this end, new dies have been fabricated, Nb half-cells have been deep drawn using the new dies, and electron beam welding parameters have been developed. We have taken this opportunity to incorporate techniques that will ultimately reduce cavity fabrication costs, such as: reducing the wall thickness by a factor of 2 to save material, eliminating one stage of the forming operation, simplifying the costly machining operations at the mating surfaces between the cavity parts and perfecting beam welding parameters that allow all cylindrically symmetrical welds to be carried out in a single pump-down of the weld box. The latter is a substantial gain over current welding practice in which weld sequences are frequently interrupted by parameter and fixture changes, repeated inspections and repeated mechanical and chemical work over joint areas.

Toward the objectives of advancing the performance of cavities, we have invested heavily in resources for basic studies that seek to characterize the detailed nature of field emission and surface resistance. We have developed advanced thermometry based diagnostic systems for locating residual losses and field emission sources. We have constructed a clean UHV furnace facility for heat treating cavities upto 1470 C, and installed a SEM/EDX system for dedicated use on SRF topics.

**Field Emission Studies**

Emitters have been studied using high purity Nb single cell 1500 Mhz cavities equipped with the new thermometry system (Fig. 3) which has 684 sensors capable of scanning the entire outer surface of the cavity within a few seconds[15]. Operation of this rapid temperature mapping system in superfluid He has been an important advance over customarily used subcooled He diagnostics, allowing high fields to be reached without thermal instabilites initiated by the poor heat transfer of subcooled He. A large number of emitters have been located and a detailed study of their emission undertaken. The effect on emission of cycling to room temperature, exposure to clean filtered air, rf and He processing is in progress. Among the salient features, we have frequently observed emitters that switch to a highly emissive state after the rf field has been on for fractions of a second. Regions that emit strongly in one test become significantly quiet after the cavity is warmed upto room temperature and cooled down without breaking vacuum or creating mechanical disturbances.

A large ultra-high-vacuum furnace has been designed, constructed and commissioned (Fig. 4). To protect the cavity surfaces from exposure to dust after firing this furnace will be housed inside a Class 100 clean room, interconnected with the present clean room for attaching cavities to the rf test set-up for immediate evacuation.

Tests have been conducted on the effect of firing high purity Nb in our new UHV furnace. A 1200 C, 1 hour heat treatment decreased the RRR of a Nb sample from 380 to 290, corresponding to 5 ppm O pick-up. Such a drop would not appreciably degrade the stabilizing property of high thermal conductivity Nb against thermal breakdown due to defects. However a 2 hour heat treatment at 1470 C lowered the RRR from 390 to 60, which is unacceptable. Further tests are planned to determine if shorter heat treatments at the higher temperatures will be tolerable.

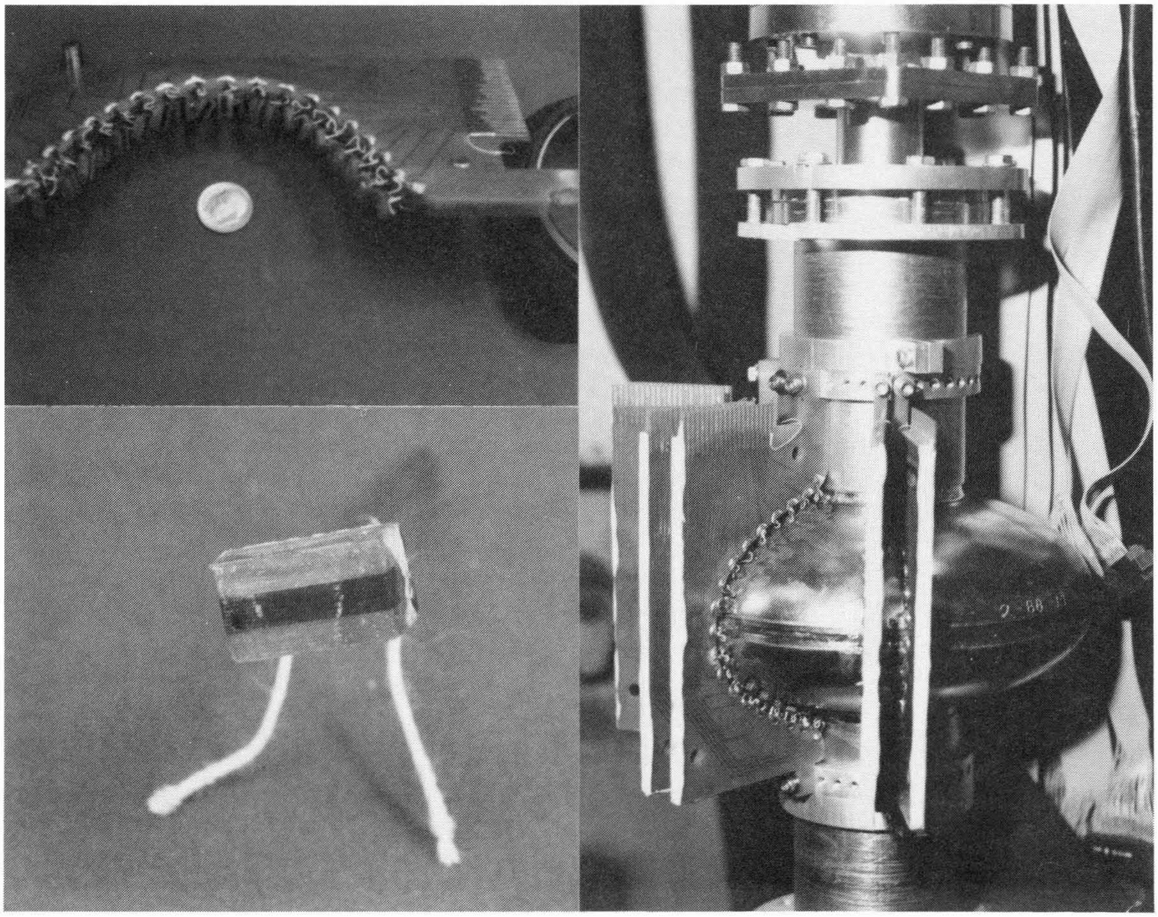

Fig. 3 Thermometry system for field emission studies.

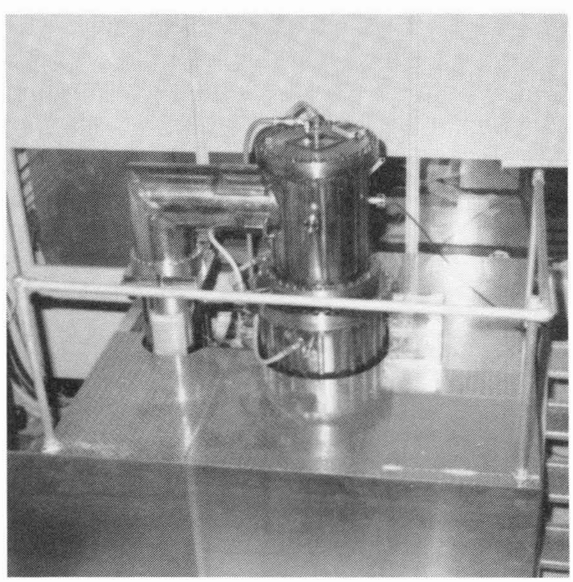

Fig. 4 Cornell UHV furnace for heat treating cavities to 1500 C.

Two single cell 1500 Mhz cavities have been fired for two hours each in our new UHV furnace, one at 1100 C and one at 1200 C. The first cavity showed a small decrease in RRR due to high temperature firing, starting at a RRR = 300 - 400, whereas the second cavity showed a drop in RRR to ~ 100, at least within the rf surface layer. Fortunately this was not significant or deep enough to trigger a thermal breakdown during the rf test. RF testing was carried out in conjunction with our high speed superfluid thermometry diagnostic system to provide detailed information on field emitters. Significant field emission activity was present in both fired cavities, but after short periods of He processing (5 - 15 minutes) maximum surface electric fields of 33 Mv/m (825 Oe) could be reached in both cavities at Q values of 2 -3 $x10^9$. Both tests showed improvement over the emission limited field values achieved when the same cavities were prepared by standard chemical treatment and without any firing (21 and 26 MV/m). Fig 5 compares temperature maps between fired and chemically prepared surfaces for the same field level. For a multi-cell cavity with the same geometry and beam hole opening, the maximum surface electric (magnetic) field reaced would allow accelerating fields of 13.5 (17.6) Mev/m. Both tests on fired and unfired cavities were limited by frequent trips of the radiation detectors, due to the intensity of high energy X-rays emanating from the cavities. Further tests are planned to ascertain whether the suggested benefit due to heat treatment can be realized on a more statistically significant sample, and whether prolonged He processing or high temperature firing can be used to reach even higher fields.

## Residual Surface Resistance Studies

A lower limit of 1-2 nΩ has been ascertained for the contribution to the residual resistance of naturally occurring oxides of Nb[16]. 8.6 Ghz cavities have been fired at 1400 C to dissolve the oxide layer into the bulk, as confirmed by companion Auger studies on Nb samples, and are sealed to maintain the oxide free state. RF tests in this state show a residual resistance level of 5 -10 nΩ. Oxide layers, subsequently grown on these "clean" surfaces by controlled exposure to 0.1 torr oxygen for two days, do not show any increase in residual losses. The definitive presence of oxide on the surface is established by reabsorbing the oxide at 300 C within the first few μm of the rf surface and observing correlated changes in the electron mean free path, transition temperature and the residual resistance. For eg, heating an oxidized surface to 300 C decreases the electron mean free path by a factor of 10, increases the residual resistance by 40 nΩ and lowers $T_c$ by 0.4 K. Oxide free surfaces show none of these effects on heating to 300 C. The nature of the 5-10 nΩ losses on the oxide free surface remains unknown, however. These losses are equal in magnitude to losses expected from the BCS theory at 1.33 K, and are roughly 1/3 the value that is usually obtained with standard chemical cleaning techniques.

To systematically investigate the spatial distribution of the residual resistance and its dependence of surface treatments, a demountable flat end-plate of a $TE_{011}$ cavity has been scanned with an array of 100 super-sensitive thermometers(Fig 6). Temperature maps have been attained in superfluid He at 1.5 K. (See Fig. 7) 50 nΩ lossy regions can be located, corresponding to a Q value of $6x10^9$. Three kinds of losses have been distinguished: localized spots, wide patches and losses due to spurious RF currents crossing the indium joint[17].

For these surface resistance studies, we have developed very sensitive thermometers for use in superfluid He . Key ingredients have been the ability to isolate the thermometer from the superfluid bath and to establish intimate contact between the sensor and the outer cavity wall. By incorporating a phase-lock technique the detection sensitivity has been improved 3 orders of magnitude over subcooled He diagnostic

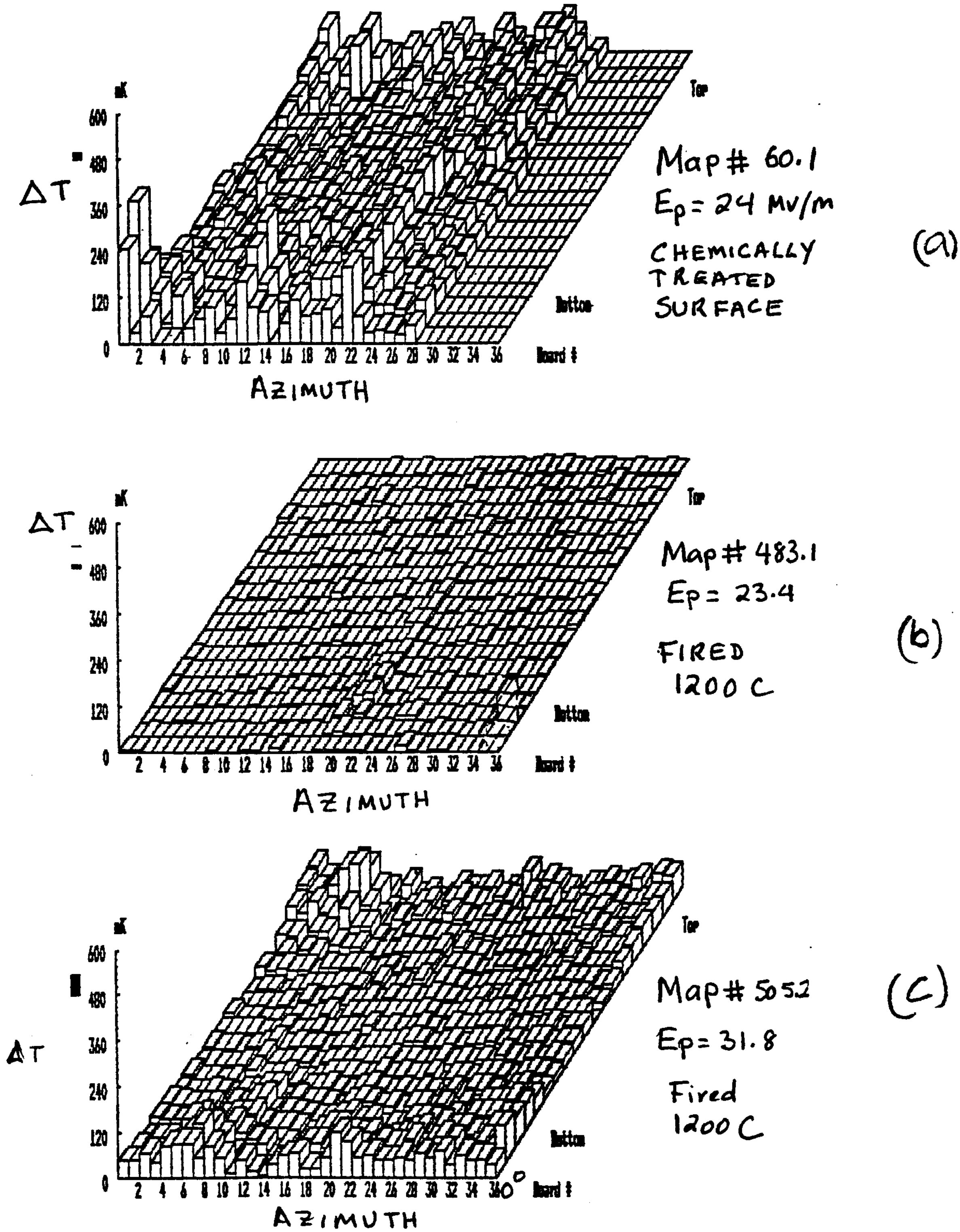


Fig. 5 Comparison of temperature maps between chemically prepared cavity and fired cavity at the same field level (a) and (b), and a T-map near the highest field level for the fired cavity (c).

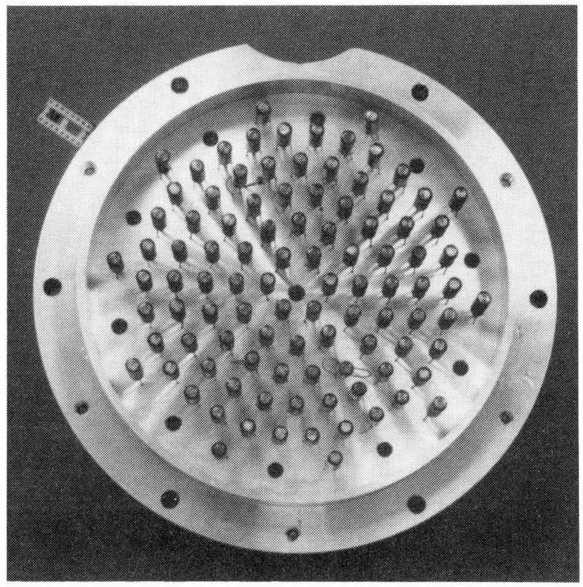

Fig. 6 Thermometry system for surface resistance studies

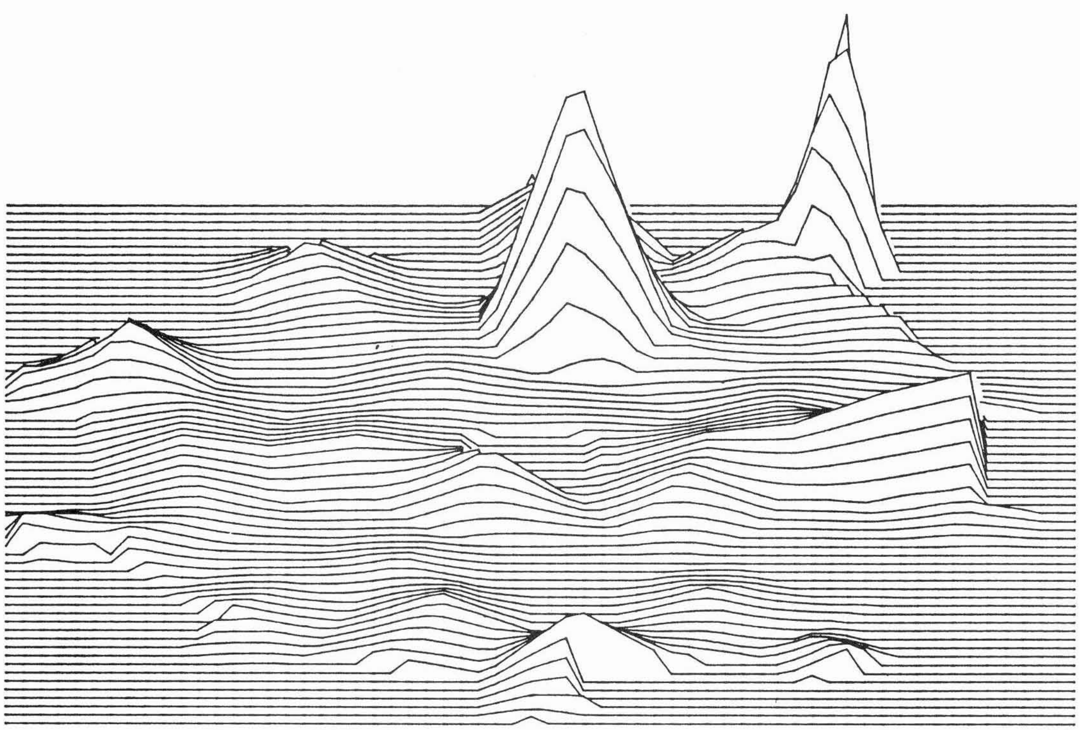


Fig. 7 Temperature map from surface resistance study.

techniques. 10 μK temperature increments are now measurable, so that nΩ residual losses are discernable if 200 Oe magnetic fields can be imposed on the rf surface.

These improvements in the sensivity of spatially resolved thermometry indicate that the time is ripe for correlating rf losses located by thermometry with a characterization of local surface condition with a surface analytical tool. To study lossy areas detected by thermometry systems we have installed, in a class 1000 clean room, a scanning electron microscope /energy dispersive X-ray elemental analysis system. The microscope is equipped with a large (28x28x28 cm) chamber so that any point on the surface of a 15 cm diameter disk can be viewed in a single pump-down through available stage motions which are motor controlled and programmable to allow systematic searches . The chamber is turbo-pumped so that surface cleanliness can be maintained. The X-ray system permits quantitative analysis down to atomic number 5 which will prove crucial for sorting out the role of various mechanisms responsible for residual losses : processing residue, surface dust, chemical and physical inhomogeneities of the bulk or inclusions in the base material.

## High Purity Nb Studies

We have continued to stimulate the Nb producing industry to maintain the recent progress in commercially available high purity Nb. We have performed calculations on the kinetics of oxygen and nitrogen outgassing during electron beam melting, as well as detailed analysis of residual impurities found in commercial high purity Nb from various suppliers[18]. The unreliability of traditional methods of light interstitial element analysis at the 1 to 10 ppm level has spurred us to fulfill the analytical need by a treatment and measurement program that estimates the impurity levels by measuring the RRRs after selectively removing oxygen by solid state gettering, and after removing nitrogen by outgasing at 2200 C in an ultra high vacuum. These studies reveal that oxygen is still the major culprit and that total nitrogen and carbon contents below 10 ppm are now achieved on an industrial scale[18]. For the Nb producing industry, these studies signify that after the first few melts in the electron beam furnace, the pay-off in higher RRR is more likely to come from improving the base vacuum rather than by increasing the number of melts. In view of the persistent prevalence of oxygen, the technique of solid state gettering, applied at Cornell[10] continues to provide substantial gains in purity after production. RRR values upto 700 have been obtained after yttrifying 1/8" thick Heraeus Nb.

The solid state gettering purification technique for Nb, originally discovered with yttrium has been extended to be used with titanium[19]. Both single cell as well as 5-cell cavities have been treated with Ti after fabrication and measurement. In all cases field values improved substantially after thermal conductivity improvement with Ti treatment, and thermal breakdown was never observed after the treatment.

## High Purity Nb 1-cell Cavities and 5-cell Structures

Cavities have been manufactured from high purity Nb from most major suppliers, as well as after further purification by solid state gettering with Y or Ti. Both single-cell cavities as well as full scale structures with couplers have been tested. 14 high purity Nb 1-cell cavities and eight high RRR 5-cell structures have been tested extensively. The RRR values ranged from 100 - 400. Single cell cavities reached surface fields between 15 and 42 Mv/m (375 and 1050 Oe) and 5-cell cavities reached accelerating fields between 5 and 15 Mev/m. Residual Q values between $3x10^9$ and $3x10^{11}$ are achieved. A selection of results is shown in Fig 8 for 1 cells and Fig 9 for structures. The spread in the low field residual resistance values is shown in Fig.10 .

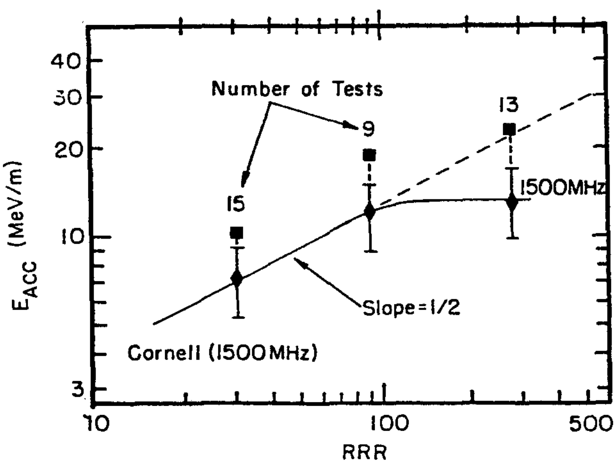


Fig. 8 Single cell cavity results.

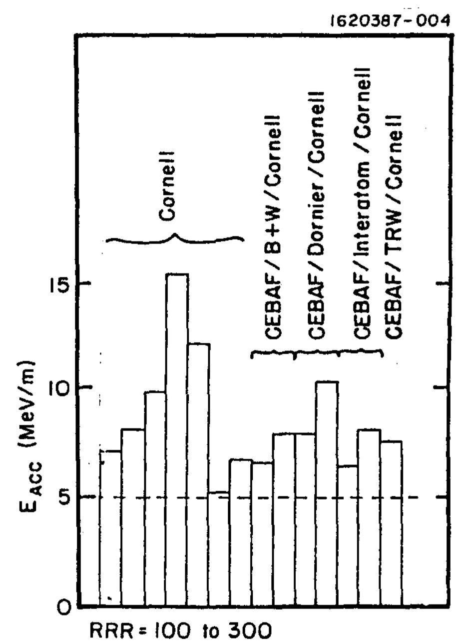


Fig. 9 5-cell cavity results.

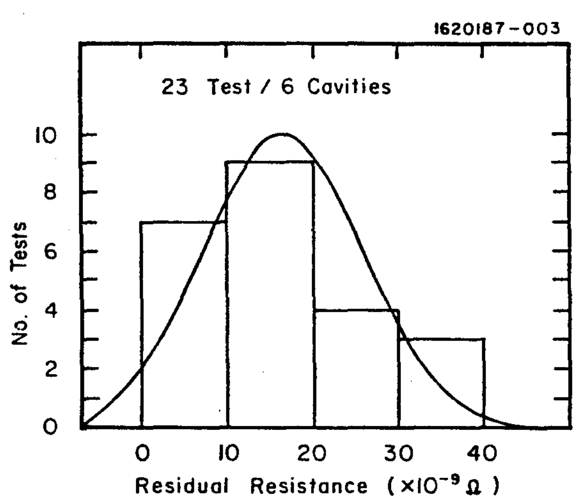


Fig. 10 Distribution of residual resistance values for 1-cell 1500 Mhz cavities.

### Bronze-Processed $Nb_3Sn$

1μm thick stoichiometric and homogeneous $Nb_3Sn$ surfaces with onset $T_c$ of 17.7 K and $\Delta T_c$ as low as 200 mK were prepared on Nb substrates by the bronze method. The samples were prepared by depositing layers of Cu, Sn and Cu on chemically polished Nb substrates using electron beam evaporation. The composites were subsequently reacted at 800 C. Application of this process to 3 mm thick sheet, high purity Nb substrates (RRR = 200 - 600) resulted in no significant loss of RRR, because the reaction temperature is 800 C instead of 1100 C. However prelimnary rf results were not encouraging because not all areas of the cavity could be uniformly covered. [20]

### Studies on the New High $T_c$ Superconductors

The exciting discovery of high $T_c$ superconductors [9] has naturally opened exploration on the possibility of application of oxide superconductors to microwave cavities for particle accelerators. We are collaborating with the Cornell Physics and Applied Physics Departments which have supplied us with 1/2" diameter pellets of single phase Y-Ba-Cu-O superconductor and single crystal flakes. We have performed inductive measurements of the superconducting transition on the pellets showing an onset of 92 K and a transition width of 2 -3 K. SEM studies show the material to have grain size of 5-10 μm. Quantitative EDX (energy dispersive X-ray) elemental analysis show that the average compositions of Y, Ba and Cu correspond to the correct stoichiometry for the $Y_1Ba_2Cu_3$ superconducting phase.

A special test vehicle has been constructed for evaluating the microwave properties of high $T_c$ disk shaped samples upto 0.5" diameter. (Fig. 11). A 6 Ghz Nb cavity of the $TE_{011}$ type has a cut-off tube into which a sapphire rod carrying the sample on one end is inserted, until the sample is flush with a current carrying surface. As the test cavity is maintained at 4.2 K, it's Q remains high, while the temperature of the sample can be varied independently between 300 and 4.2 K by heaters at the opposite end of the sapphire rod. The Q of the Nb test cavity with the sapphire rod/heater/thermometer assembly, but without the sample, is measured to be $7x10^7$ at 4.2 K, close to the expected value. The Q further increased by a factor of 4 when the cavity was cooled to 2 K. A Nb pellet identical in shape to the sintered powder pellet showed no measureable effect on the cavity Q at 4.2 K, demonstrating that the residual resistance contribution of the teflon holder used and the small spot of Apiezon N grease placed under the pellet for thermal bonding is negligible. With the Nb pellet at 300 K and the rest of the cavity at 4.2 K, the surface resistance of Nb is used to calibrate the fields at the pellet. Between 10 and 6 K it was possible to measure the decrease of Nb surface resitance from the normal conducting value $1.2 x10^{-2}$ Ω to $5x10^{-5}$ Ω. By cooling the test cavity to 2 K, we expect to be able to measure $R_s$ values as low as $1x10^{-5}$ Ω in 1/2" diameter sample, if the need arises by the availability of good material.

A calorimetric technique for determining low values of $R_s$ was also demonstrated. Using RF power alone, it was possible to maintain a differential between the pellet and bath temperatures of 0.5 K. The amount of power required to achieve the same temperature increment was then determined by using the heater alone. From this power and the high temperature field calibration, the $R_s$ value of Nb at 4.7 K was meausured to be $1.6x10^{-5}$ Ω. Given our capability to reliably measure a 0.1 K temperature differential, we expect that the calorimetric method can yield values of $R_s$ as low as $3x10^{-6}$ Ω with the test cavity operating at 4.2 K.

Our first rf test on a 1/2" diameter pellet of Y-Ba-Cu-O has been carried out. At 6 Ghz, the surface resistance dropped by a factor of 60 between 90 and 4.2 K, reaching a

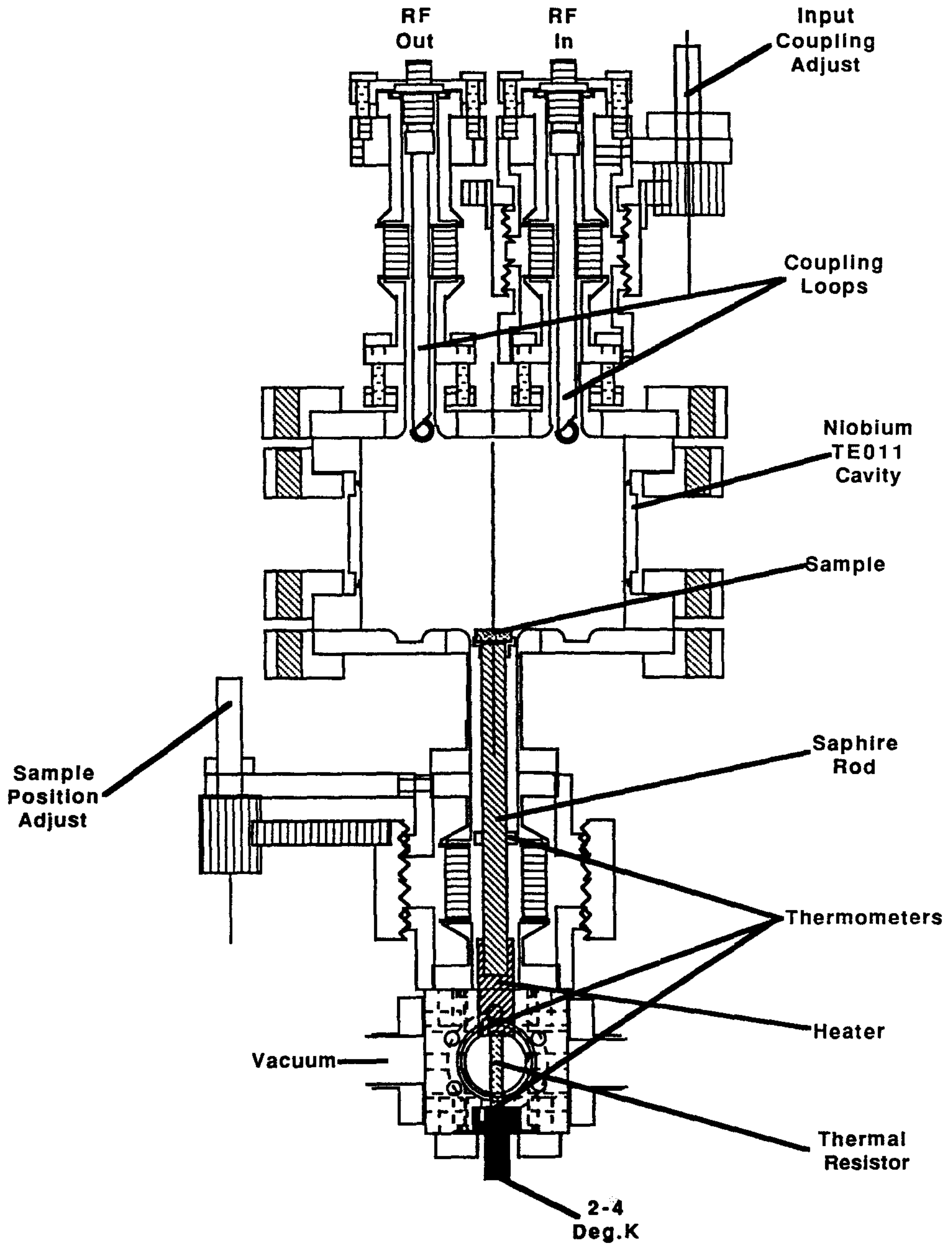


Fig. 11 Test cavity for high $T_c$ material.

residual resistance of 0.02 Ω. As the applied field was increased between 1/2 and 12 Oe, , the resistance increased sharply to 2Ω.

10 small single crystal flakes which have the c-axis perpendicular to the plane of the flake were glued with paraffin on to the end of the sapphire rod and inserted into our $TE_{011}$ high $T_c$ test cavity. A superconducting to normal transition could be measured around 80 K. In the normal state of the flakes, the Q of the 4.2 K Nb cavity was lowered by only a factor of 28 instead of a factor of 640 drop obtained with the normal

conducting, larger area sintered pellet. Because of the reduced sensitivity (reduced area), the Q of the test cavity returned to the full Q of a 4.2 K Nb cavity when the flakes were cooled to 4.2 K, so we were unable to determine the full improvement factor. Since we obtained the full Nb Q at 4.2 K, we judge that the paraffin glue did not cause significant rf losses.

A larger single crystal flake (3mm x 1mm) was then inserted into an 8.6 Ghz Nb elliptical cavity. The flake was placed in the highest magnetic field region of the cavity (at the equator) and the cavity was tested in the horizontal position, so the flake would not dislodge. Before insertion of the flake, the cavity reached a Q of $2 \times 10^9$, and after, it reached a Q of $2 \times 10^8$ at 1.5 K. A similar size flake of highly resistive normal conducting material in a copper cavity was used to calibrate the effect on the Q of a copper cavity. From this calibration, we ascertain the resdual resistance of the single crystal Y-Ba-Cu-O flake to be $< 9.7 \times 10^{-5}\ \Omega$. This is a factor of 200 lower than the residual resistance of the sintered powder pellet we measured.

SEM studies of the flakes showed some aluminum contamination probably from the alumina boat, while EDX studies showed the correct $Y_1Ba_2Cu_3$ stoichiometry, as well as good agreement with the stoichiometry of the sintered powder pellet. In the future we hope to further improve the flake by annealing in oxygen.

## Future Activities

Soon after completion of our second storage ring beam test, we embarked upon a program to address the dominant problems in rf superconductivity. Our primary objective is to advance the current capabilites of superconducting cavities from 5 -10 Mev/m to the needed capabilites of E > 30 Mev/m at Q values over $10^{10}$ for TeV scale linear colliders.

Our future program will heavily utilize the systems we have built to study field emission and surface resistance and to study the influence of various surface preparation techniques. We hope to seek ways to upgrade performance. We also plan to extend our program of accelerator physics and design studies on structures for superconducting TeV linear colliders. Twin objectives of a suitable structure design will be to fulfil the requirements imposed by beam dynamics, and to incorporate simplifications that would reduce unit costs. Improvements in fabrication technology that permit high quality cavities to be made more easily and cheaply will be pursued. Although our main effort will focus on Nb, exploratory work on the new high Tc superconductors will continue. As a next step we are preparing to measure epitaxially grown films as well as single crystals. Measurements will be made at various frequencies from 1.5 to 12 Ghz.

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