RESEARCH AND RESEARCH SUPPORT—Dr. Quark Chen, research associate professor (*l.*), and Lian Xue, doctoral student in computer science, study devices which will help miniaturize and improve imaging devices. This research is being conducted in the laboratories of Dr. Wei-Kan Chu, TCSUH, and Dr. Jaroslaw Wosik, where investigators are studying rf and dc flux in YBCO thin films.

Magneto-Optical Imaging of rf and dc Flux in YBCO Thin Films; Correlation with the rf Power Handling Capability

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Abstract— Scientists have not achieved a fundamental understanding of the nonlinear phenomena responsible for microwave losses and of high rf power limitations. UH research scientists utilize a magneto-optical technique[2] to visualize the dynamics of dc and rf fluxes penetrating weak links of YBCO films at the high rf power level. This methodology allows researchers to study correlation between the film microstructure, rf and dc fluxes leaking through the YBCO films defects at higher rf power levels.

The system consists of two parts: (1) the optical cryostat, where the sample (YBCO film) and an optical indicator are mounted, and (2) the polarizing microscope with an image recording system.

This project integrated the magneto-optical imaging system with a microwave resonator in order to obtain real time images of the rf flux penetrating film defects at high rf power levels. With a unique pulsed system for characterizing microwave power handling capability, using a transient measurement method already designed in UH laboratories, researchers can measure dynamics of the changes in surface impedance attributed to the applied high power.

IN SPITE OF A GREAT BODY OF EXPERIMENTAL DATA ON THE SURface resistance of high-T_C superconductors (HTS) and several reported studies on the power dependence of HTS surface resistance, scientists have not achieved a fundamental understanding of the nonlinear phenomena responsible for microwave losses and of high rf power limitations.[1] This is contrary to the low-T_c superconducting materials, where defects were eventually identified as being responsible for the nonlinear behavior. The performance-degrading effects in superconducting niobium microwave cavities by high rf fields have been studied in the past. Researchers found that local and global Joule self-heating have an influence on the rf breakdown. Microwave current patterns are determined by a resonator mode preventing the current from meandering and initiating local heating within one or more localized point defects or/and planar defects. At these locations, the temperature rises and eventually may even trigger the quenching process. Such a process always initializes penetration of weak links by the rf flux. At this point, magnetic and thermal components causing nonlinearity cannot be easily distinguished.

We use a magneto-optical technique[2] to visualize the dynamics of dc and rf fluxes penetrating weak links of YBCO films at the high rf power level. This methodology allows us to study correlation between the film microstructure, rf and dc fluxes leaking through the YBCO films defects at higher rf power levels.

The project is a collaboration of a team of investigators including Dr. J. Wosik, Dr. W.-K. Chu, and Dr. Q. Chen at TCSUH. Facilities used for this project include the magneto-optical imaging system (Dr. W.-K. Chu's Lab), microwave device and characterization and the HTS thin film deposition lab (Dr. J. Wosik).

For this project, the magneto-optical imaging system was integrated with a microwave resonator in order to obtain real time images of the rf flux penetrating film defects at high rf power levels. A sketch of the experimental set-up is shown in Fig. 1. We have redesigned two different resonators: a dielectric sapphire cavity and a microstrip ring resonator.

The system consists of two parts: (1) the optical cryostat, where the sample (YBCO film) and an optical indicator are mounted, and (2) the polarizing microscope with an image recording system. First, a TE_{011} mode dielectric cavity operating at 14 GHz was integrated with the optical cryostat. Two YBCO thin films, large enough to cover the 18-mm diameter cavity enclosure, were placed on both sides of a 9 mm × 5 mm sapphire disc. For such a design, almost 98 percent of the microwave power is dissipated in the films. The cavity and both films are cooled with a gas flow cryostat designed for high rf power measurements. The system is designed such to ensure the same temperature of both films during the measurements. It guarantees that the cavity is able to achieve a very high quality factor-Q at low temperatures. Such a Q factor, for levels of the microwave power available in our lab is equivalent to the rf field in the film exceeding lower rf critical field B_{c1}. The cryostat has two SMAconnector feedthroughs for a HP vector analyzer or for a high power microwave system to be connected.

Figure 2 shows the details of the configuration in which an optical indicator is placed on the top of YBCO film. Such indicator consists of the Bi:YIG 5 μm-thick single crystal film produced by liquid epitaxial growth on a 0.5 mm-thick gadolinium-garnet (GGG) substrate.

Such a substrate is transparent to the intense green light (546 nm) used in the microscope. This substrate has also low microwave loss, as was verified recently in our lab. The imaging sensor is coated with a 0.13 mm *Al*-film protected by a 0.2 mm thick layer of Ti_3N_4. The indicator can provide a Faraday rotation up to ten degrees. The sensitivity of the system is about 1 Gauss and the spatial resolution for some cases can be below 1 μm.

A leak of the flux induced by the presence of a weak link causes the magnetization vector in Bi:YIG film to tilt. The perpendicular component of the magnetization, which is parallel to the beam light, introduces a Faraday rotation resulting in the lightening of the local image of the investigated YBCO film. For the case of YBCO films thinner than the penetration depth, we should see images related to the rf current distribution.

The indicator response time is of the order of picosecond; thus it is fast enough to sense the rf field at the range of GHz frequencies. A Faraday rotation angle depends on whether the rf H field is parallel or anti-parallel to the light beam direction. Consequently the Faraday angle during one microwave cycle changes from $+Q_F$ to $-Q_F$. However, the intensity of the polarized light beam measured after the analyzer, will be proportional to cosine of Q_F. For both directions of the rf field perpendicular to the film surface, the camera will capture the same change in the light intensity. This is a key element, which makes the idea of the magneto-optical imaging in rf fields feasible. In principal, using this method, we should be able to record a change of the rf field of the order of 1 Gauss with the resolution close to 1 micron.[2]

Results

Experimental methodology needed for the microwave measurements is already well developed in TCSUH laboratories and has

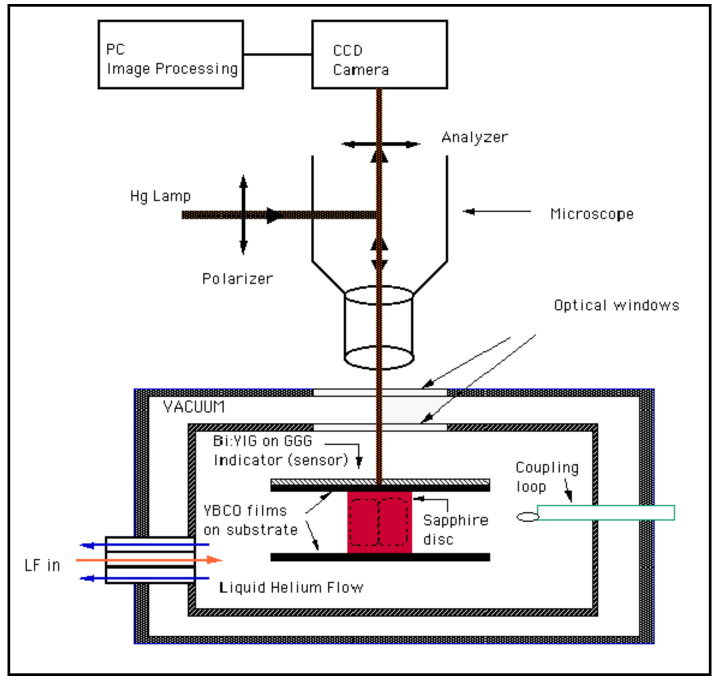

Figure 1. Schematically shown is the magneto-optical imaging system and the cryostat integrated with a sapphire dielectric cavity.

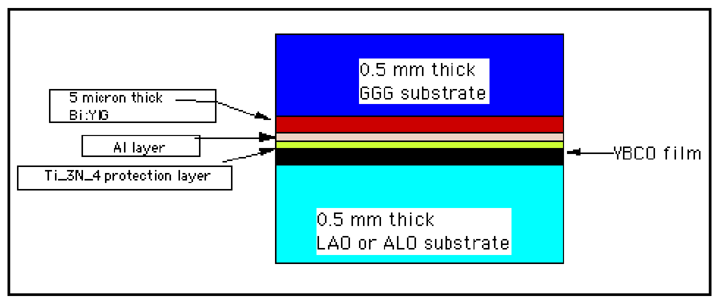

Figure 2. The Bi:YIG indicator is shown on the top of YBCO film on *$LaAlO_3$* substrate.

formed the basis for many publications.[3] A unique pulsed system for characterizing microwave power handling capability, using a transient measurement method, has been already designed in our laboratory. Using this method, we can measure dynamics of the changes in surface impedance attributed to the applied high power.

For this part of the project, we have redesigned both resonators to fit into a special shroud of the gas flow cryostat (Janis). Either the dielectric cavity or microstrip resonator can be attached to the cold head of the cryostat using a special holder. The shroud with two optical windows was fabricated for this project in TCSUH machine shop.

We have completed assembly of the whole system, and we have already carried out preliminary tests at several rf power levels. In Fig. 4, two magneto-optical images are shown for the experiment in which, first, the superconducting structure was cooled down at zero dc magnetic field to 5 K and, then, the dc magnetic field of 20 mT was applied. Higher density of the screening current is clearly seen (Fig. 4b) as a bright ring on the outer perimeter compared with that on the inner edge. The higher density indicates that the superconducting strip ring expels the flux from the inside of the ring. Fig. 4b shows the current distribution after the dc magnetic field was switched off. This time, the flux is trapped inside of the ring.

References

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[3]J. Wosik, L. M. Xie, R. Grabovickic, T. Hogan, and S. A. Long. "Microwave Power-Handling Capability of HTS Superconducting Thin Films: Weak Links and Thermal Effects Induced Limitation," IEEE *Trans. on Applied Superconductivity* 9 (1999): 3294-97.

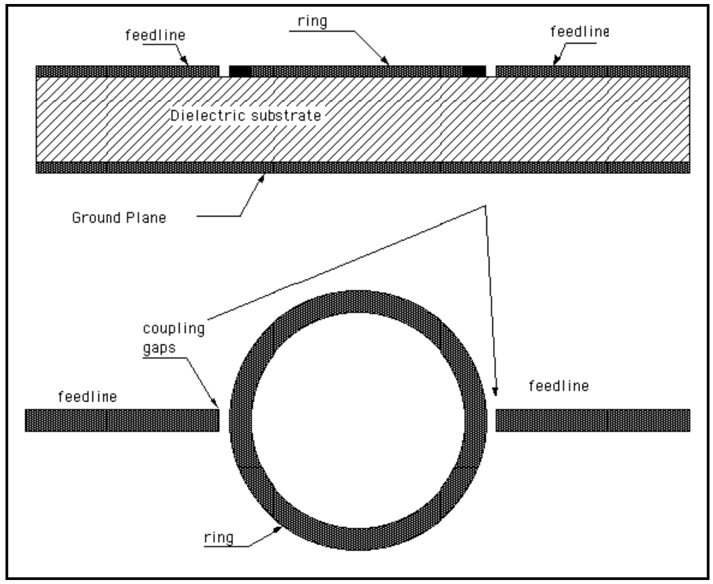

Figure 3. The microstrip ring resonator was designed for magneto-optical imaging. The feed-lines for signal –in and –out are shown as well as two gaps forthe capacitive coupling. The thickness of the substrate is 0.5 mm, YBCO film thickness is 0.5 micron and the line-width is 1 mm.

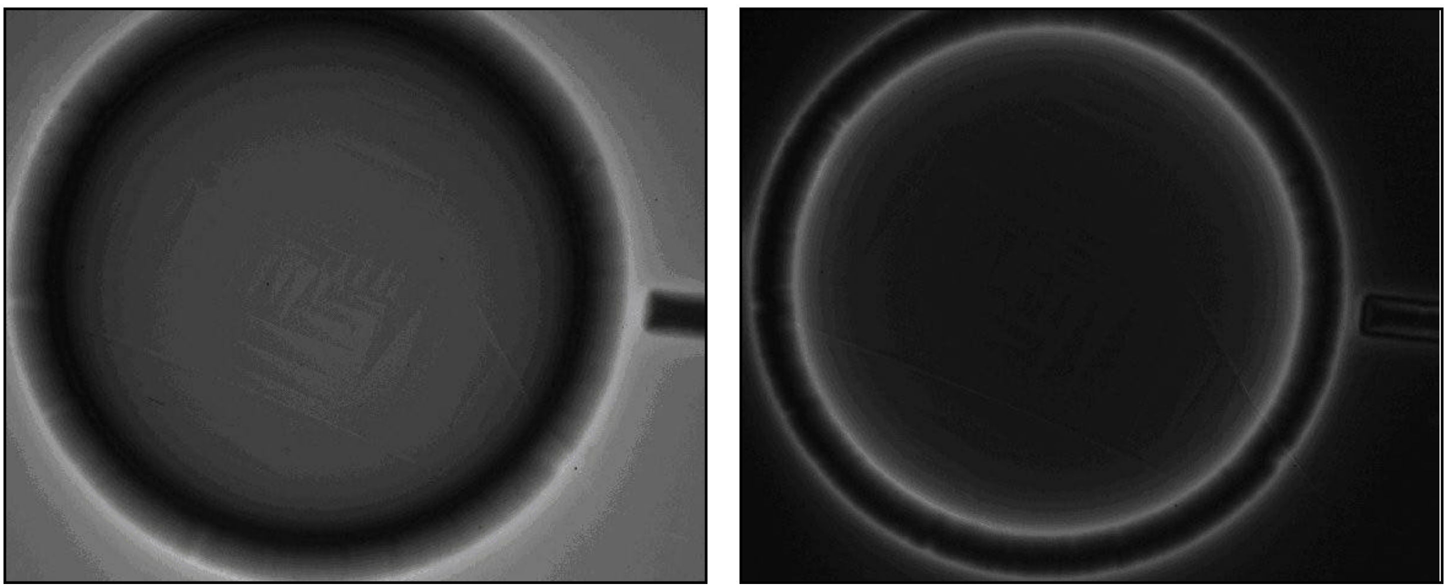

Figure 4. Magneto-optical images of a superconducting microstrip ring (see Fig. 3). (a) After zero field cooling to 5 K, dc magnetic field was applied to induce the current in the superconducting ring. (b) Current distribution in the ring is shown after removing the dc field.

Publications

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Funding and proposals

"Dielectric Spectroscopy for the Detection of Biological and Chemical Warfare Agents." PI: J. Miller, Co-PI: J. Wosik and M. Benedik; $196,000; *pending*.

"Investigation of Superconducting YBCO Film rf Nonlinearities at MHz Frequencies; MRI Transmittal Coil Study." Co-PI: S. Wright, Texas A&M; ARP Texas Coordinating High Education Board 2001 Program, $170,000; *not funded*.