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TESTCHIP FOR HIGH TEMPERATURE SUPERCONDUCTOR PASSIVE DEVICES

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ABSTRACT

A testchip for a full characterisation of High Temperature Superconducting (HTS) thin film properties relevant to planar passive microwave device applications is presented. The chip integrates coplanar resonators and transmission lines along with structures for process monitoring.

Measurements of the quality factor of coplanar resonators as a function of temperature and input power are reported. For the coupling of the resonators to the input signals microwave probes with 40GHz bandwidth have been used within the cryo-enviroment. Quality values obtained at 5GHz and 77K are superior to that of an equivalent copper resonator by a factor of about 40.

INTRODUCTION

Fabrication of High Temperature Superconducting (HTS) devices requires the developement of key technologies such as deposition of epitaxial thin films with high critical current densities, low surface resistance at microwave frequencies and a good long term stability, patterning techniques for micrometer structures while non effecting to the superconducting state, methods for making of low resistance Ohmic contacts and many more.

The functioning of a device is critically dependent on the outcome of these technologies and improvements can only be made if a full and complete characterization of every single fabricated device can be obtained. As material and other properties may vary from batch to batch it is essential that all structures necessary for characterization are incorporated within the same mask and at the same time transfered to the HTS thin film.

The notion of a "test chip" is familiar in microelectronic design. We report here on the design and the realization of a test chip for HTS devices with our interest mainly focussed on passive planar microwave devices such as resonator filters and transmission lines.

TEST CHIP LAYOUT

The standardized size of our substrate materials is 10x10x0.5mm.

In the test chip layout this area is partitioned into specific structures for device studies and for material and technological characterization (fig.1).

Resonator Structures

Incorporated are $\lambda/2$ coplanar resonators with different center frequencies in the GHz-range together with inductive coupling structures.

Coplanar Transmission Lines

HTS transmission lines have promising applications as chip to chip interconnects as they can propagate electric pulses of very high bandwidths with virtually no dispersion. Different designs are used here.

Critical Current Density Monitor

This structures serve for the measurement of the critical temperature T_c and the DC critical current density using a four-point probe geometry.

Ohmic Contacts

Contact resistances obtained by different fabrication process parameters can be studied.

Structures for Etch Control and -Monitoring

Mask Alignement Structures

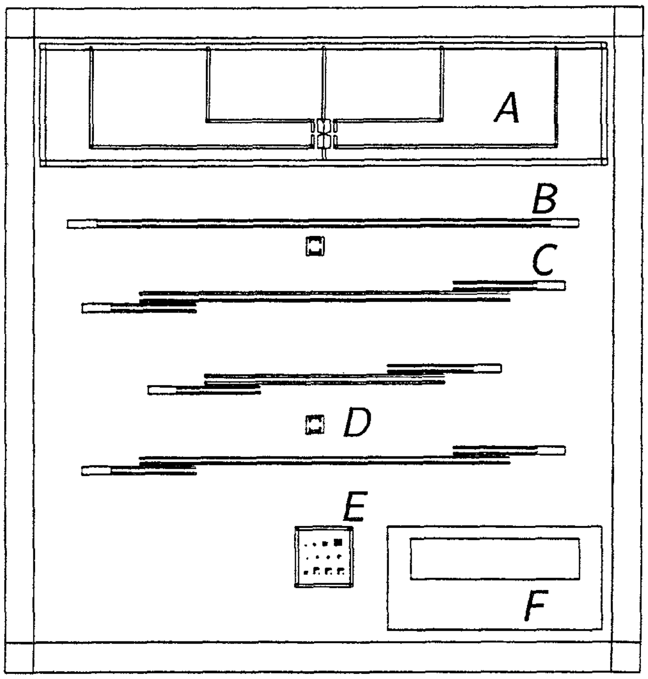

Fig.1. Layout of the testchip for HTS passive devices. Specific test structures for microwave resonators(C), transmission lines(B), critical temperature and critical current density(A), Ohmic contacts(F), etch monitoring(E) and mask alignement(D) are contained in the designated areas.

In the design great care has been taken to avoid any mutual interference of structures with one another. This was especially important for the arrangement of the microwave resonator structures.

Before HTS thin films are structured a series of non-destructive characterization measurements is done: among them are X-ray diffraction to check the epitaxial crystal growth, inductive determination of Critical Temperature values and measurements of the surface resistance at microwave frequencies which is a crucial factor for microwave applications. As all these measurements cannot be done at the same location it was also required to devise a standardized packaging scheme for HTS thin films which enables the transportation of samples in a controlled and reproducible manner.

The coplanar structures have been patterned on laser ablated $YBa_2Cu_3O_{7-x}$-thin films epitaxially grown on $LaAlO_3$ substrates. Weak phosphoric acid has been used as the etching agent.

MICROWAVE EXPERIMENTAL

The performance of a resonator is described by its quality factor Q_0, which in our coplanar geometry is composed of the quality factor Q_c due to conductor losses, Q_r to radiation, and Q_d to losses from the dielectric substrate.

$$\frac{1}{Q_0} = \frac{1}{Q_c} + \frac{1}{Q_r} + \frac{1}{Q_d}$$

Radiation losses can be reduced on the expense of a lower Q_c by choosing smaller lateral waveguide dimensions(1). In our case a radiation quality factor of 12000 has been calculated. The dielectric quality factor Q_d is approximately given by the inverse of the loss tangent of the substrate. Only a small number of substrate materials are available to grow epitaxial HTS thin films. Among them $LaAlO_3$ and MgO were found to be also suitable for microwave applications. The dielectric quality factors are in the order of 10000 and 3000 respectively at frequencies of 9GHz at 77K(4). High purity of the crystal is probably a decisive factor in obtaining high Q_ds.
Due to the kinetic inductance of the superconducting carriers ohmic losses occur at non-zero frequencies. The losses are caused by single electrons excited across the superconducting gap. The microwave surface resistance R_s directly determines the conduction quality value Q_c which can be described as

$$Q_c = g/R_s,$$

where g is a geometry dependent factor that can be calculated in a quasi static approach(2). The value of Q_c also includes influences of structural defects of the superconductor material, such as grain boundaries, twinning, point defects, surface roughness and possibly information on yet unknown intrinsic properties.
Other than measurements of surface resistance within a microwave cavity however, micrometer structure resonators as proposed in our test chip

are more sensitive to losses that are vital to actual applications such as losses due to patterning, current crowding at line edges and interface properties which renders it possible to trace back some of the mechanisms that lead to losses. Therefore, planar resonator structures with HTS material have already been the object of extensive studies (5,6,7,8).
In our measurement set up the sample mounted within a Helium gas cooled cryostat, the high frequency signal is fed to the device by coplanar microwave probes with 40GHz bandwidth (fig.2).

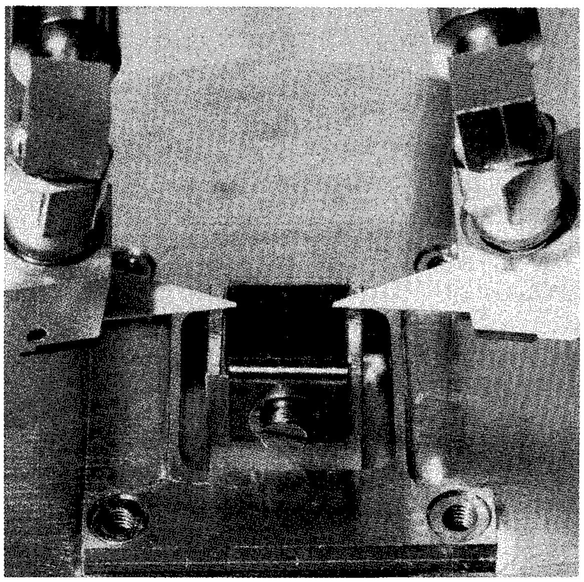

Fig.2. Testchip for HTS passive devices in measurement housing within a Helium gas cooled cryostat. High Frequency Signals are fed to the structures under test by means of 40GHz coplanar probes.

Figs.3 shows the dependance of the resonator quality factor and the resonance frequency on temperature. Laser ablated thin films of $YBa_2Cu_3O_{7-x}$ of different batches have been used as the conductor material. In Fig.3a the thin film has shown a superconducting transition at 90K with a width of 0.5K and a critical current density of 5 $10^6 A/cm^2$, slightly higher than the value for the material used for the resonator in fig.3b, which had a superconducting transition at 90K with a width of 1.3K and a critical current density of 2 $10^6 A/cm^2$.

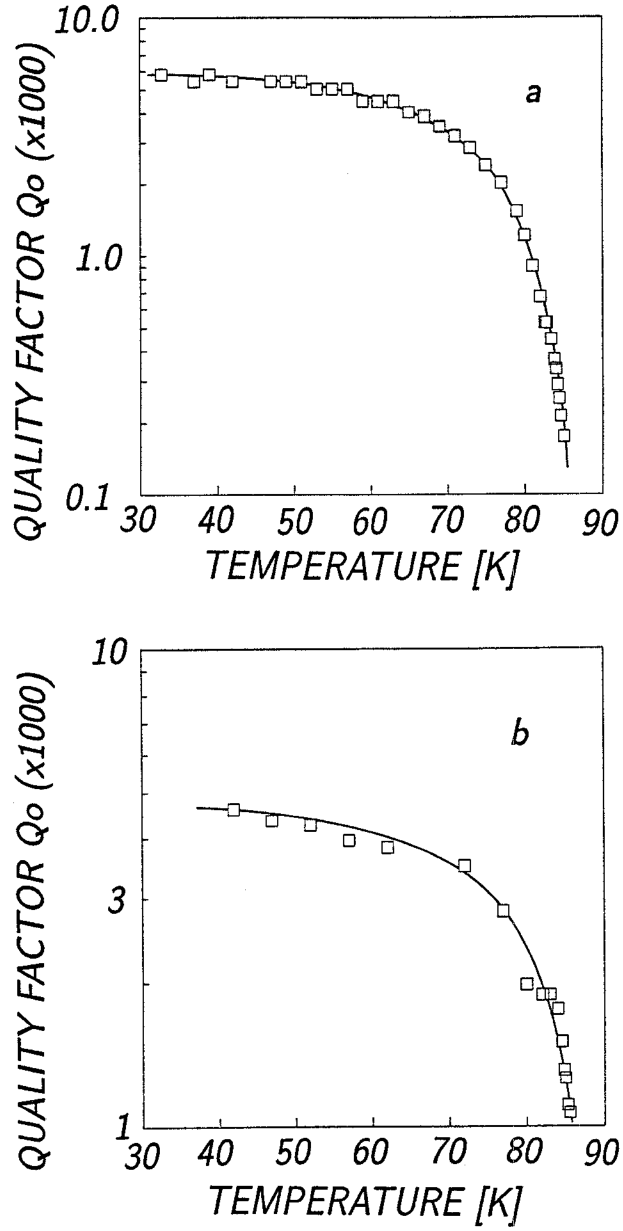

Fig.3. Dependance of the quality factor of coplanar resonators on temperature, conductor material: laser ablated $YBa_2Cu_3O_{7-x}$ thin film of 300nm thickness, (a)material with a critical temperature of 90K, 0.5K transition width and a critical current density of 5 $10^6 A/cm^2$, (b)material width a critical temperature of 90K, 1.3K transistion width and 2 $10^6 A/cm^2$ critical current density.

Both resonators exhibit a quality factor of about 3000 at 77K for the respective resonance frequencies 6.5GHz (fig.3a) and 5.2GHz (fig.3b). At temperatures around 40K the quality factors increase to 5800 (fig.3a) and 4700 (fig.3b).

The resonator quality at three different temperatures shows no significant degradation with increasing dissipated power (fig.4). The power related maximum current densities J_{0max} have only been limited by the available power from our driving source. So the critical current densities might be even higher. To our knowledge this are the first measurements of such high current densities at microwave frequency.

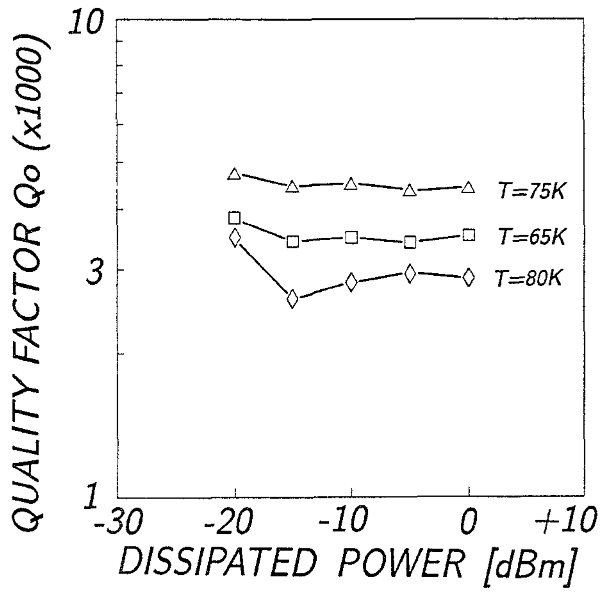

Fig.4. Dependance of the resonator quality factor on dissipated power, material as given in fig.3b.

Current densities of 1.6 $10^6 A/cm^2$ at 6.5GHz have been observed.

Regarding attainable surface resistances of $YBa_2Cu_3O_{7-x}$(3) still higher performances of these resonators seem to be possible. This requires a careful evaluation and control of all parameters leading to better film and substrate quality especially the microstructure of the superconductor and etching and patterning techniques are an issue. In our test chip a full set of characterzations can be done on the very same thin film from which the planare resonator has been structured. Transition temperature and DC critical current which are sensitive to structural defects of the HTS material can be measured, the patterning process can be verified with specific structures which allow the determination of surface roughness and edge corrugation. Also, several planar resonator structures with different geometries allow measurements at different resonator frequencies without unpreceded changes of material parameters. Correlations between microstructure and resonator performance are thus made possible.

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