MEASUREMENTS OF ε AND μ OF LOSSY MATERIALS FOR THE LOW TEMPERATURE HOM LOAD

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INTRODUCTION

In high current storage rings with superconducting cavities strong broadband HOM damping has been achieved by using beam-pipe ferrite loads, located at room temperature [1]. Adopting the same damping concept for the ERL with RF absorbers between the cavities in a cavity string will require operating the absorbers at a temperature of about 80 K. This temperature is high enough to intercepted HOM power with good cryogenic efficiency, and is low enough to simplify the thermal transition to the cavities at 2 K. However, the electromagnetic properties of possible absorber materials were not well known at cryogenic temperatures. Therefore, we started a measurement program at Cornell to find possible absorbers for HOMs in the ERL. First results for ferrites TT2-111R, HexM3 and HexMZ in the frequency range from 1 to 17 GHz were presented earlier [2, 3]. Now preliminary measurements were done for 10 different materials up to 40 GHz.

MATERIALS

We examined 10 different materials listed in the Table 1. Not all of them were measured in the whole frequency range because of absence of some samples with the necessary shape; they are marked by “minus” (-) in the table. Some materials appeared to be very brittle (C48-E1, C48-E2) and cannot be recommended for further usage in our project.

Table 1. Materials and frequency ranges where they were measured.

Freq., GHz / Material	1-12.4	12.4-18	18-26.5	26.5-40
TT2-111R	+	+	+	+
C48-E1	+	-	+	+
C48-E2	+	-	+	+
HexM1	+	+	+	+
HexM2	+	+	+	+
HexM3	+	+	+	+
HexMZ	+	+	+	+
ZR10CB5	-	+	+	+
ZR20CB5	-	+	+	+
Z7YL	-	+	-	+

The tested materials fall into 3 groups: ferrites TT2-111R, C48-E1, C48-E2, hexagonal phase ferrites M1, M2, M3, and MZ [4, 5], and Ceradyne ceramics ZR10CB5, ZR20CB5, Z7YL [6, 7].

MEASUREMENTS

The measurement procedure is described in [2, 3]. For measurements of *S*-parameters in the region 12.4-40 GHz the network analyzer Agilent 8722ES was used. So, the whole range from 1 to 40 GHz was covered by measurements with a coaxial line (7/3.05 mm, 1-15 GHz, HP8720 network analyzer), and with waveguides: WR62 (12.4-18 GHz), WR42 (18-26.5 GHz), and WR28 (26.5-40 GHz). Transmission lines used for measurements and samples to be measured are shown in Fig. 1.

Fig. 1. Transmission lines for 4 frequency ranges.

The schematic of measurement is shown in Fig. 2. Two long waveguides were used with a short waveguide section between them for each of 3 frequency ranges. Short waveguides helped to decrease the errors connected with evaluation of the phase shift for the complex *S*-parameters. The calibration of the analyzer before measurements of cold samples was also performed with cooled lines having transitions from the cold from one end waveguides to warm adapters with coaxial cables to the analyzer. It appeared that the changes of the line length and change of the dielectric constant of N_2 (data for air were used) nearly compensated each other at 80 K in a definition of the phase angles. However, these effects should be taken into account especially for the long coaxial line. Position of the sample in the line, “insertion distance”, was defined by numerical comparison of complex reflections from each side: S_{11} and S_{22}. Before cooling the waveguides were blown through with nitrogen and the experiment was housed under positive pressure of nitrogen atmosphere (inside a plastic bag) to prevent ice formation on the cooled parts. Only the central part of the waveguide line with a cooled short waveguide was immersed into the bath with liquid nitrogen. Temperature

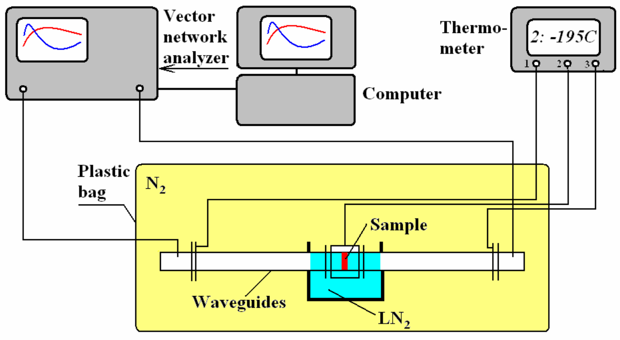

Fig. 2. Schematic of measurements.

of the central part (that was about 78÷80 K) and of the waveguide ends (170÷180 K) was checked by thermocouple thermometers. Temperature equilibrium has been achieved in 20 minutes after the start of cooling. The measured *S*-parameters were converted to complex ε and μ values following the algorithm outlined by Hartung [8].

RESULTS

We present here only a small part of obtained results (Fig. 3 - 6) because we need to continue this work with a goal to improve quality of data. The imaginary parts of both ε and μ should be negative, this means that material absorbs, not gives off, power. All data with positive Im ε or Im μ are apparently erroneous. We use on the graphs here a logarithmic scale for values –Im(ε or μ)>1, and a linear scale when these values are less than 1. Some data do not butt together at the ends of frequency ranges. This can be related not with the errors of measurements only but with difference of material properties for different batches of materials. Such a behavior was observed in data by M. Dohlus [7] for Zr20CB5 and for other materials from this group. We need to repeat these measurements with the samples made of the same batch of material. The wave length in some materials is very short, and it is difficult to avoid half-wave resonances. These measurements should be repeated with a different thickness of the samples. Some errors can be caused by irregular shape of samples; it is hard to keep right shape and small gaps between samples and waveguide walls for

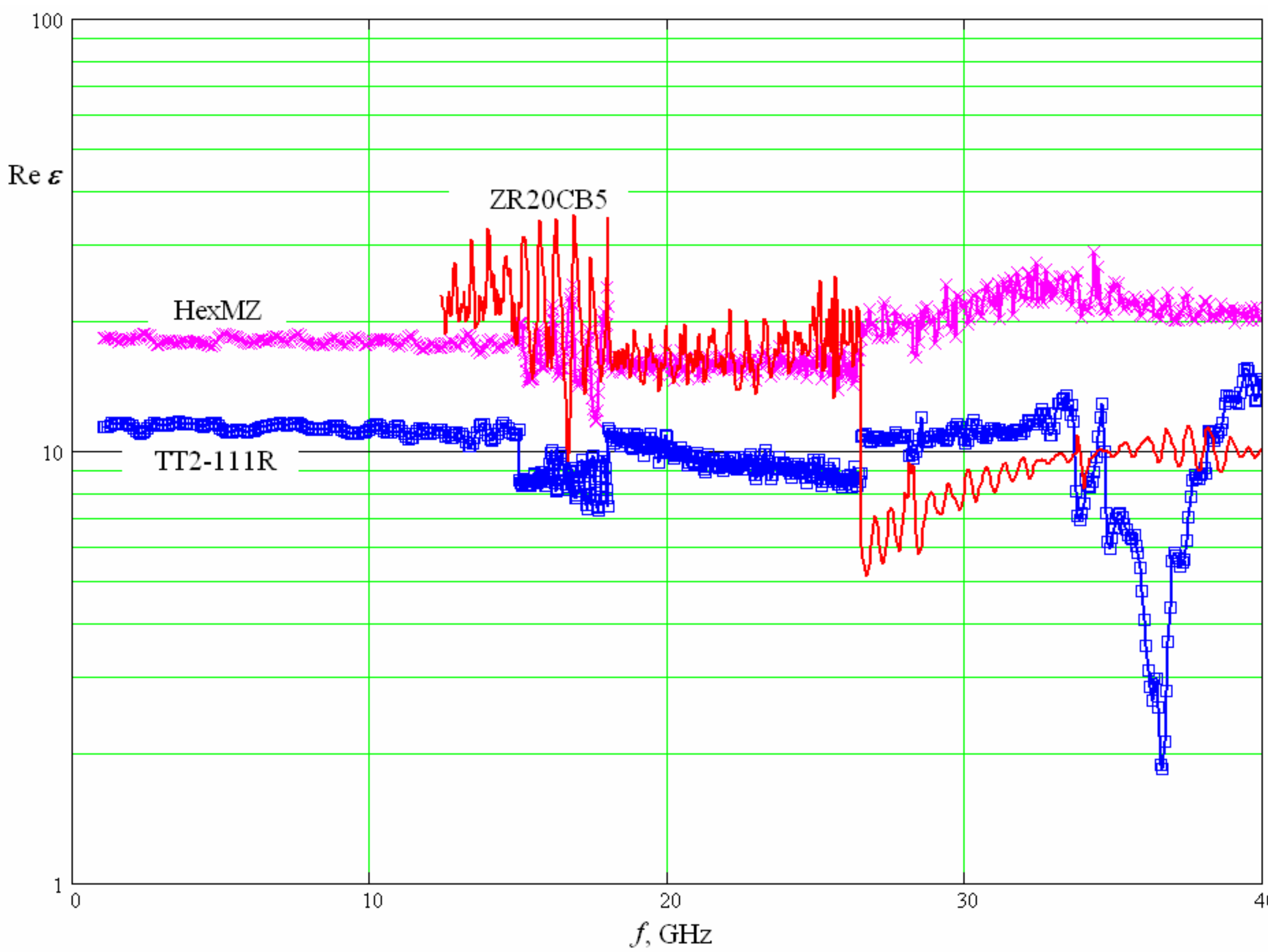

Fig. 3. Real part of ε for 3 materials from 1 to 40 GHz at 80 K.

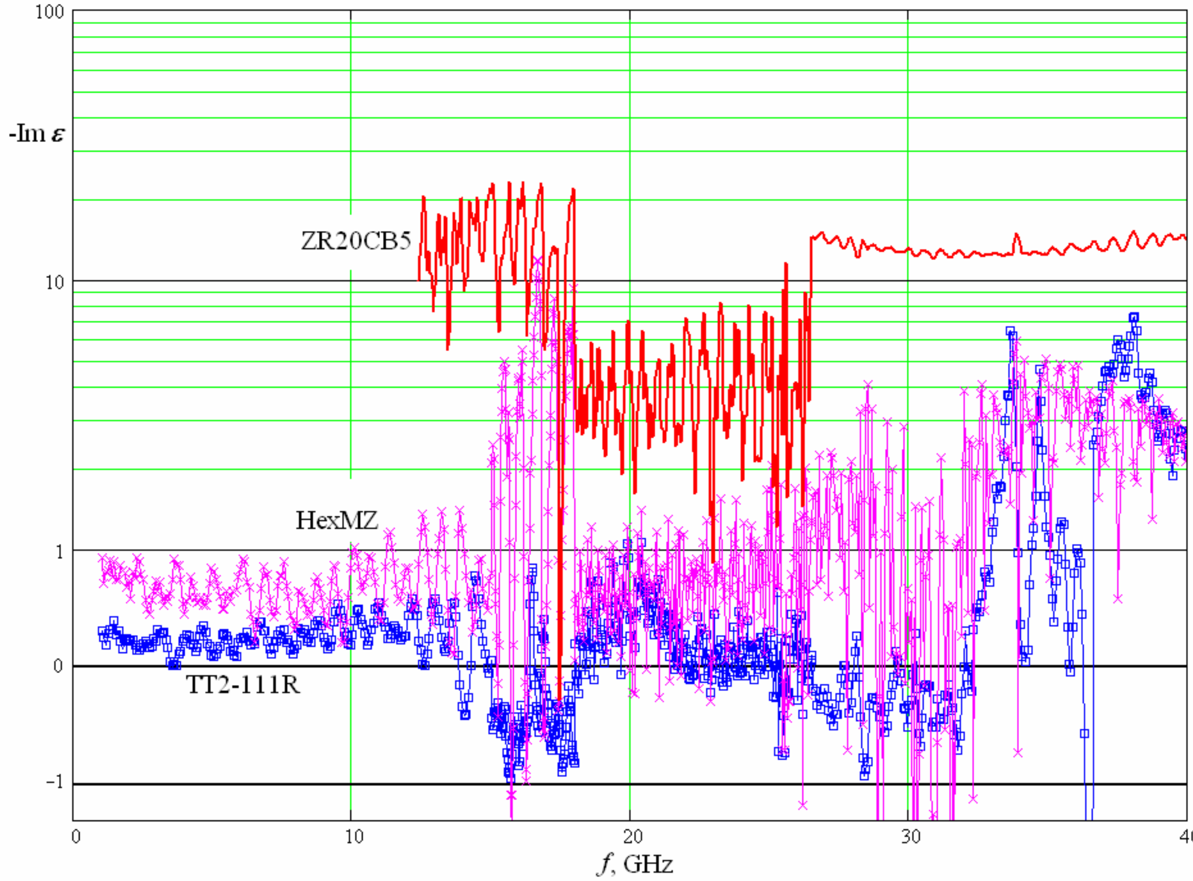

Fig. 4. Imaginary part of ε for 3 materials from 1 to 40 GHz at 80 K.

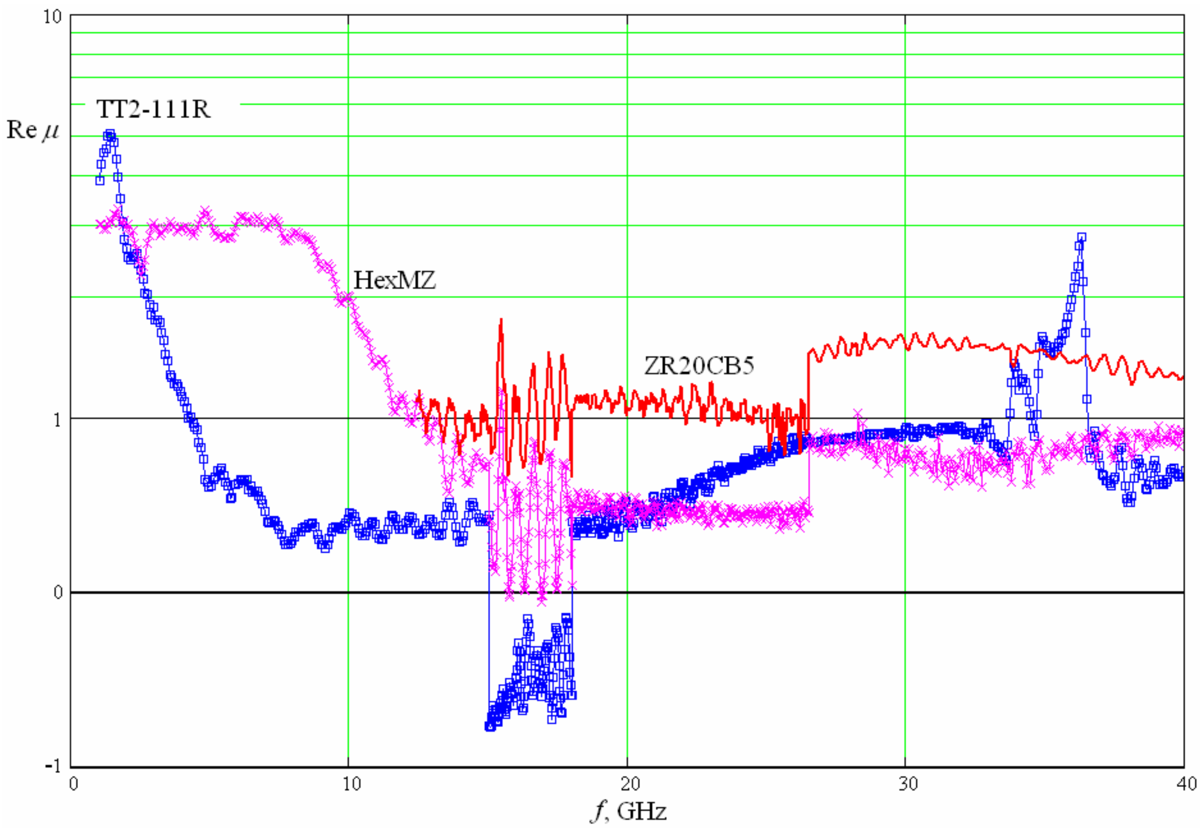

Fig. 5. Real part of μ for 3 materials from 1 to 40 GHz at 80 K.

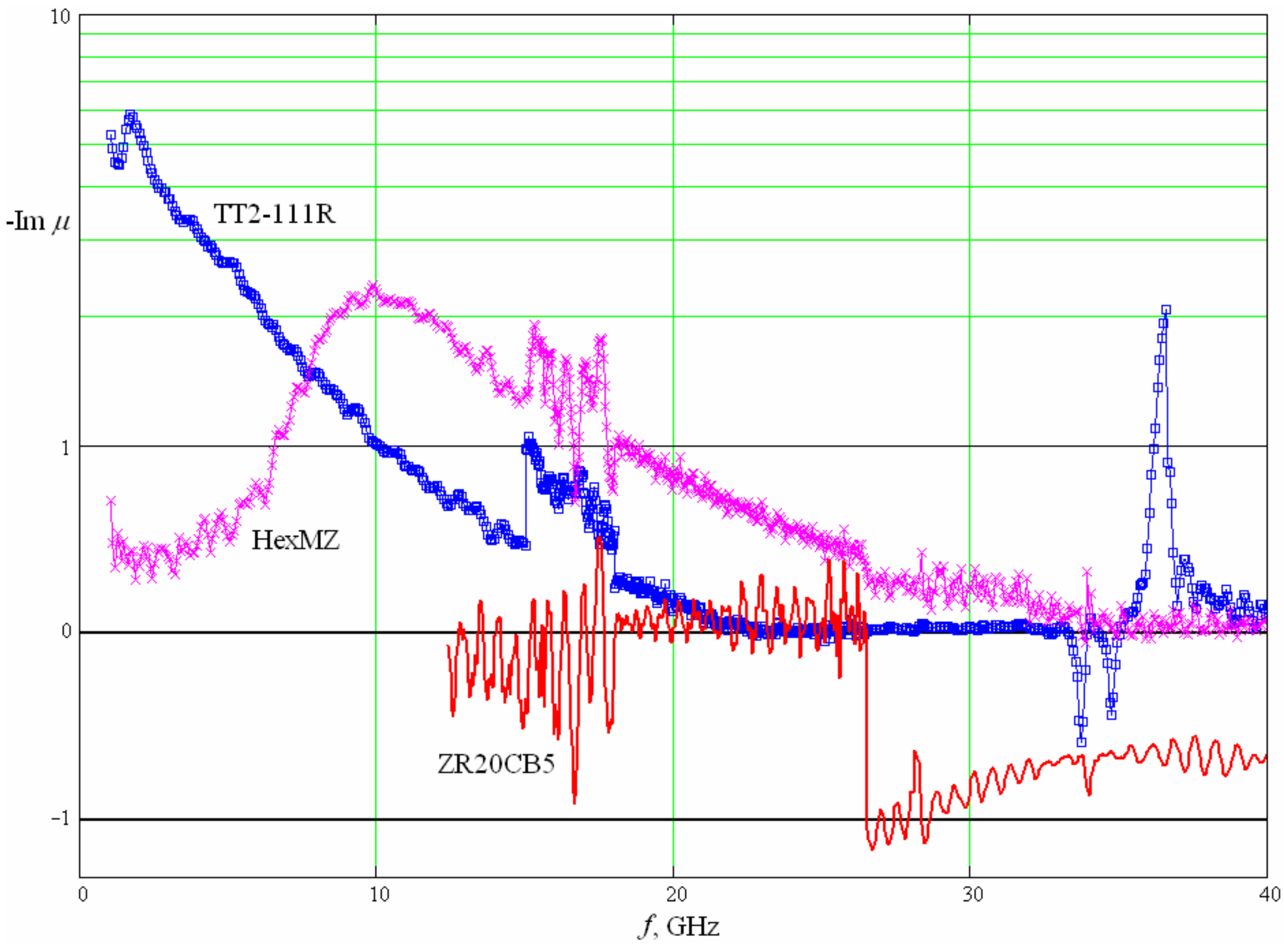

Fig. 6. Imaginary part of μ for 3 materials from 1 to 40 GHz at 80 K.

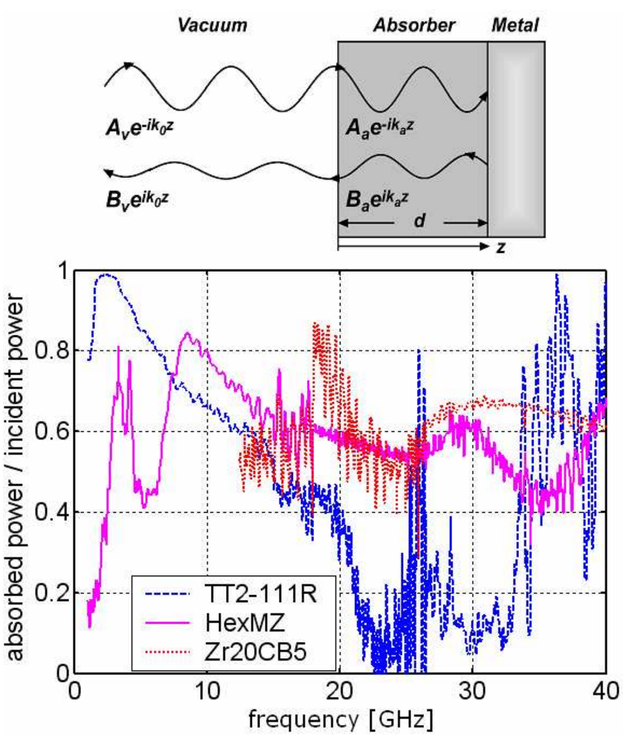

Fig. 7. Absorber model calculation (d = 3 mm) based on measured ε and μ at 80 K.

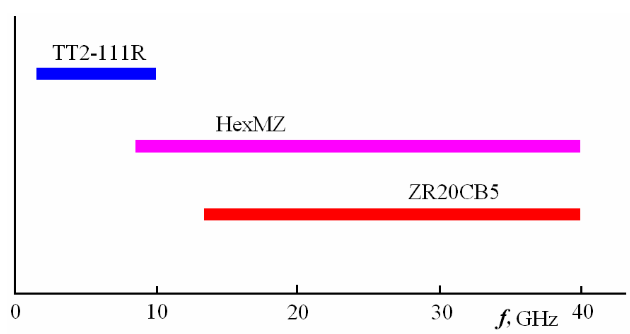

Fig. 8. Regions of application for 3 chosen materials.

so small sizes. Influence of these form deviations is planned to be studied on computer models.

However, now we have a general notion about the properties of examined materials and here are presented most promising of them. Ferrite TT2-111R can be proposed as absorbers at 80 K in the lower part of the frequency range, and ceramics like ZR20CB5 can work at higher frequencies, Fig. 7, 8. Ferrite HexMZ can work in the mean and higher frequencies. In the mean frequencies 15 – 30 GHz both HexMZ and ZR20CB5 will complement each other because the losses in them are magnetic and electric, respectively. This should help to suppress different types of HOMs.

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