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PRECISION CHARACTERIZATION OF GYROTRON WINDOW MATERIALS

Final report

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Abstract: An optical resonator has been constructed to measure dielectric properties of materials at millimeter wavelengths. The objectives are the identification and loss measurements of window materials for high power gyrotrons. The source of radiation is from a backward wave oscillator (BWO) with enhanced power, good stability, and spectral purity. The measurement technique is based on the application of a high Q Fabry-Perot resonator which provides a means of determining the difference in the reciprocal Q-factors with high accuracy. Initial loss measurements at 150 GHz at room temperature are performed on sapphire. Preliminary loss tangent results on sapphire is found to be around 10^{-4} and are reported here. Work is in progress to develop a system which will scan the resonance rapidly to produce a measurement in less than a minute and to measure the loss as a function of temperature.

Introduction: Out of various methods available to measure dielectric parameters of gyrotron window materials at millimeter wavelengths, Fabry-Perot open resonator method has been proven to be more accurate and convenient. Various theories and formulations have been developed over the years to encounter beam conformation inside the Fabry-Perot cavity. Utilization of a high-Q cavity requires a highly stable source frequency and a very sensitive detector. Millimeter wave source used for this project is a state-of -the-art backward wave oscillator (BWO) which is very stable and tunable over a wide range of frequency. For detection a highly sensitive spectrum analyzer, Tek 2782, is used.

Our newly constructed F-P open resonator system utilizes a confocal cavity with diamond-turned concave mirrors, and optimized input and output couplings are provided by a mylar beamsplitter located inside the cavity. Data collection is automated using National Instrument hardwares for data transfer with Labview 4 software. Statistical fitting and final analysis is performed by a IGOR based software developed in this laboratory.

System Diagram: The schematic diagram of the system is shown in Fig. 1. The resonator is made of two 4 in. diameter highly polished copper mirrors and of radius of curvature, R=40 cm each. Mirrors are separated by a distance, d = 65.6 cm. This makes the resonator in between confocal and spherical and d/R = 1.64. Mirrors are diamond turned and Q at 140 GHz is close to 300,000. Beamsplitters are of 25 mil mylar with 0.16% reflection at 140 GHz.

Backwardwave Oscillator (BWO): This Russian manufactured tube, model OB-86, generates millimeter wave radiation in the frequency range 110-170 GHz. It is voltage tuned which is 70 MHz/volt or 70 KHz/mV. Commercial power supply for the BWO had large ripple which resulted appreciable noise to the source. We rebuilt the power supply using DC-DC converter and eliminated ripple. Tuning voltage is controlled by a computer.

Spectrum Analyzer, Tek 2782: This device with external mixer provides a direct means of measuring linewidth. It is easy to use and we typically use the MaxHold mode when the spec. analyzer sweeps rapidly while the BWO frequency is dithered across the resonance. The spectrum analyzer captures and stores the max signal in each frequency bin to build up the envelope of the resonance curve. This takes 30 sec to 1 min. The recorded resonance curve is then transferred to the computer for analysis. The typical spec. analyzer settings for a low-loss sample are 30 KHz for both RF and video bandwidth, and the frequency span is dependent on the kind of measurement involved. The power incident on the mixer is typically 50 nW or less.

Method: All resonator techniques for measuring tanδ rely on measuring the difference between the Q_0 of the empty resonator and the loaded Q when the sample is inserted. The calculation to obtain tanδ from the difference in the Q values is somewhat complicated in the general case, but Dragin & Parshin [1] pointed out that the availability of broadly tunable BWO source allows one to simplify the calculation by judicious choice of the resonant frequency. By using the appropriate wavelength one can make the sample itself resonant.

Sample at minimum Q: This is the other condition which must be met and is also simple to accomplish. As the sample is traveled along the resonator axis, the Q is observed to vary cyclically, having a maximum when the faces of the sample are at the nodes and a minimum when they are at antinodes.

Formula used for the calculation of tanδ is given below:

$$\tan\delta = \frac{L}{\varepsilon' t}\left[\frac{1}{Q_L} - \frac{1}{Q_0}\right]$$

where L= resonant length, t= sample thickness, and ε′ = real part of dielectric constant.

Resonances: The "snap-shots" of the complete screen of the spectrum showing the resonances of the empty resonator is shown in Fig. 2, and the scales are in screen units. In this case the span is 1 GHz and the center frequency, f_0 is 136 GHz. The resonances are equally spaced, as expected at every 228 MHz.

When the sample is inserted at a frequency where it is not resonant, the effect is very apparent - the spacing of the resonances becomes unequal and are shown in Fig. 3. Tuning the BWO while tracking it with the spec. analyzer we can follow the spacings of the resonances until they become most nearly equal (Fig. 4) and thus readily locates the cavity resonance where the sample is also resonant.

Minimum Q Adjustment: This is the other adjustment which must be made to locate the sample position along the axis for the minimum Q of the cavity. This corresponds to the sample faces lying at maxima of the field.

The scan shown in Fig. 5 is of 100 MHz span and each peak is due to a sweep across the cavity resonance. However, the frequency of the resonance is not changing. Instead, the sample is moved along the axis in the 100 μm step and thus offsetting the spec. analyzer's center frequency by 10 MHz each to allow the observation of the separation of resonance peaks.

Determination of tanδ: With the conditions set as described above, the determination of Q is straight forward. Measurement of tanδ involves the measurements of linewidth of empty resonator and of loaded resonator.

Results: 1) tanδ for 1.45 mm thick sapphire

Figures 6 and 7 are resonance curves without and with sample in the resonator respectively. These are typically 30 sec scans and we average 10 such scans to obtain the result for tanδ. The Q values estimated are:

$Q_0 = 317{,}000$ and $Q_L = 158{,}000$.

Computed value for tanδ is estimated at $(1.5 \pm 0.2) \times 10^{-4}$.

2) tanδ for 1.72 thick sapphire.

Measurement was done at lower frequency to satisfy the resonant condition and the center frequency was close to 114 GHz compared to the 137 GHz in the previous case. Figures 8 and 9 are resonance curves without and with sample in the cavity respectively.

Calculation of tanδ was based on only 5 scans. The Q values are given below:

$Q_0 = 166{,}000$ and $Q_L = 96{,}000$

Loss tangent, tanδ value is estimated at $(1.5 \pm 0.3) \times 10^{-4}$.

Part of the future plan includes to fully automate the data collection system. Extend the measurements to other promising materials, such as, silicon nitride, diamond films, etc and construct a resonator structure for measurements at elevated temperatures. Measurements will be conducted at additional higher frequencies up to 300 GHz.

Reference

1. Yu. A. Dryagin and V. V. Parshin, Int. J. of IR and MM Waves **13**, 1023-1032 (1992).

MEASUREMENT SYSTEM

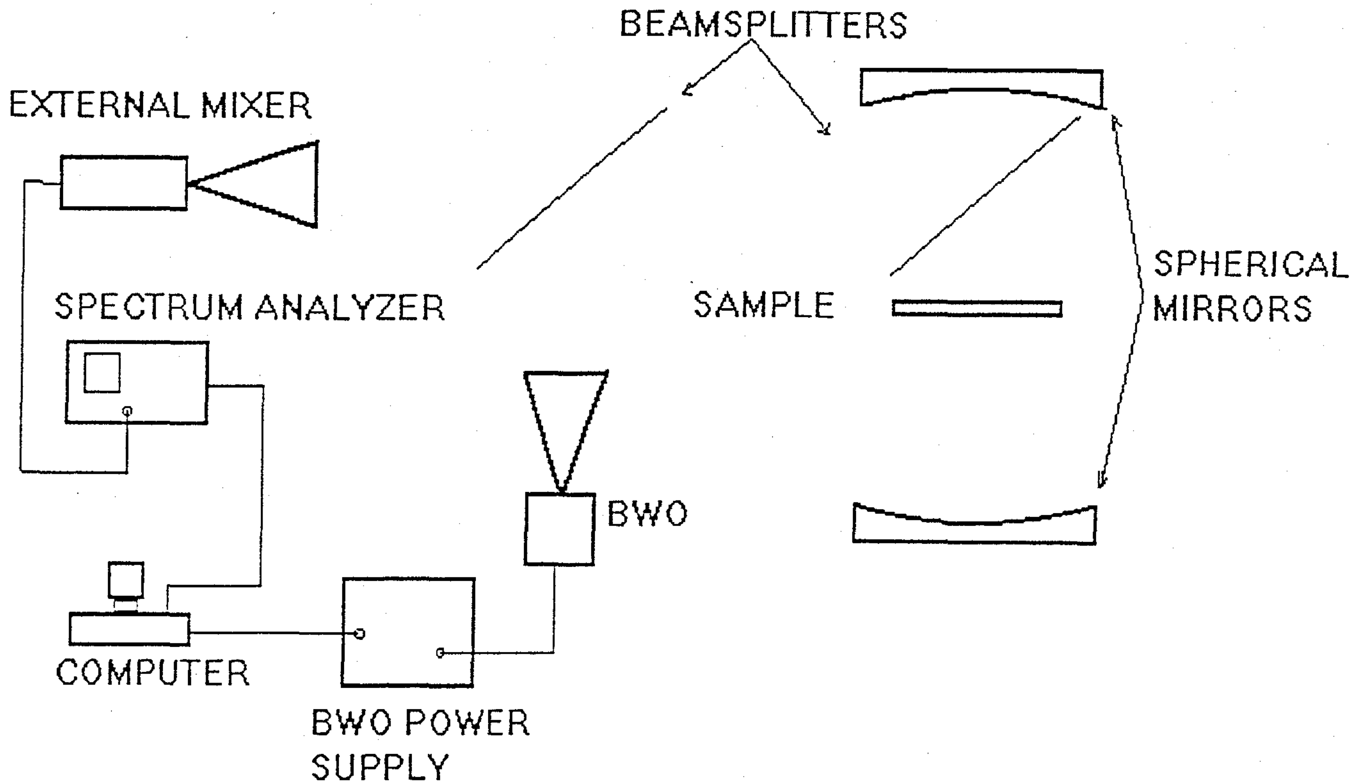

Figure 1.

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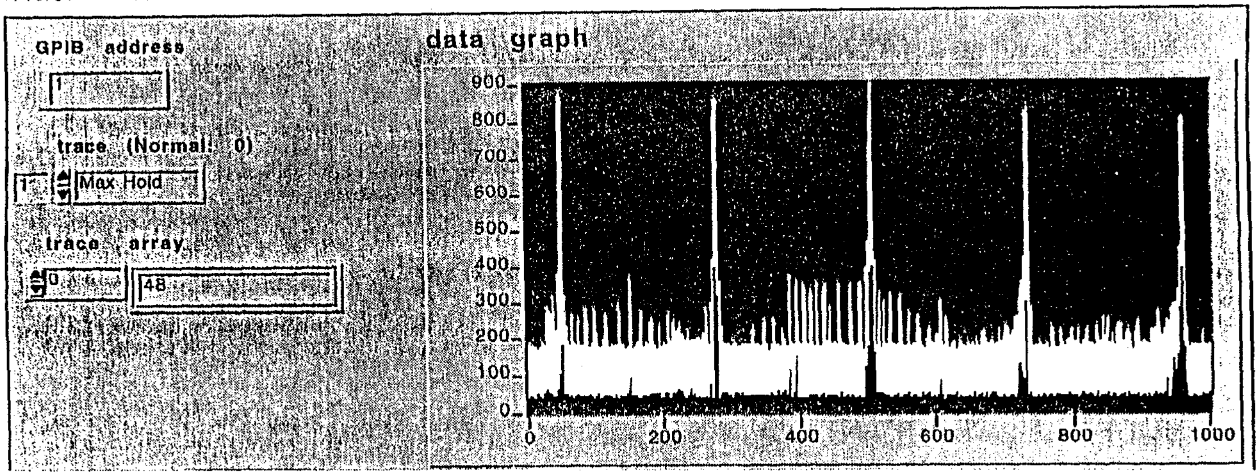

Figure 2. "Snap-shots"of resonances of the empty resonator.

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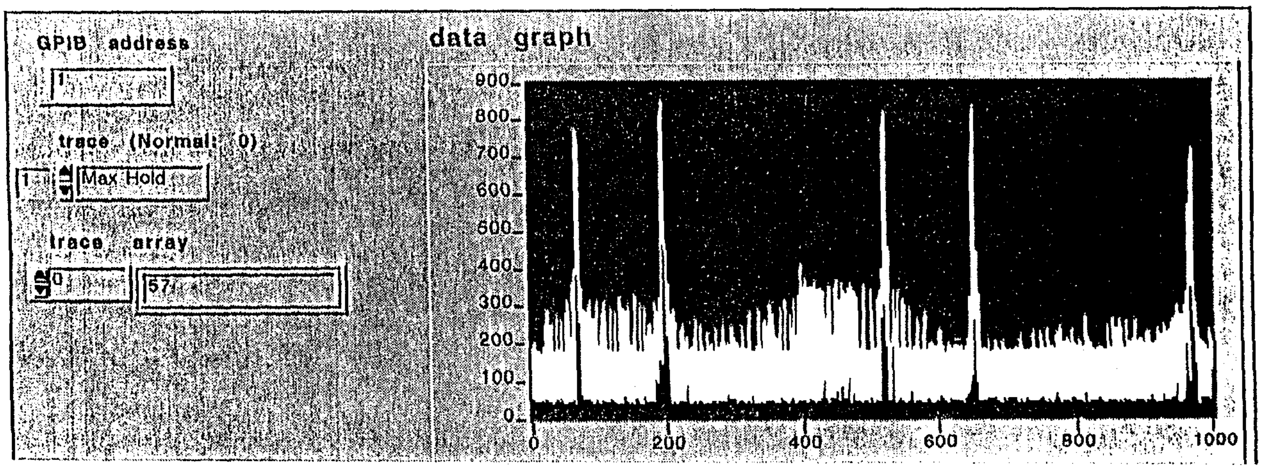

Figure 3. "Snap-shots" of resonances of loaded resonator

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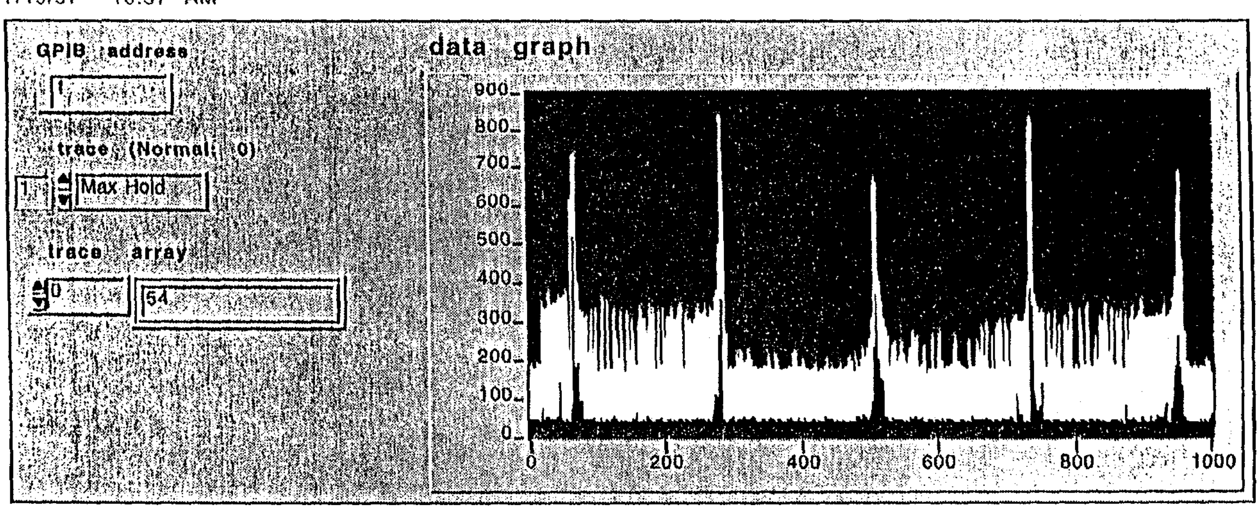

Figure 4. "Snap-shots" of resonances of loaded resonator when the sample is also resonant.

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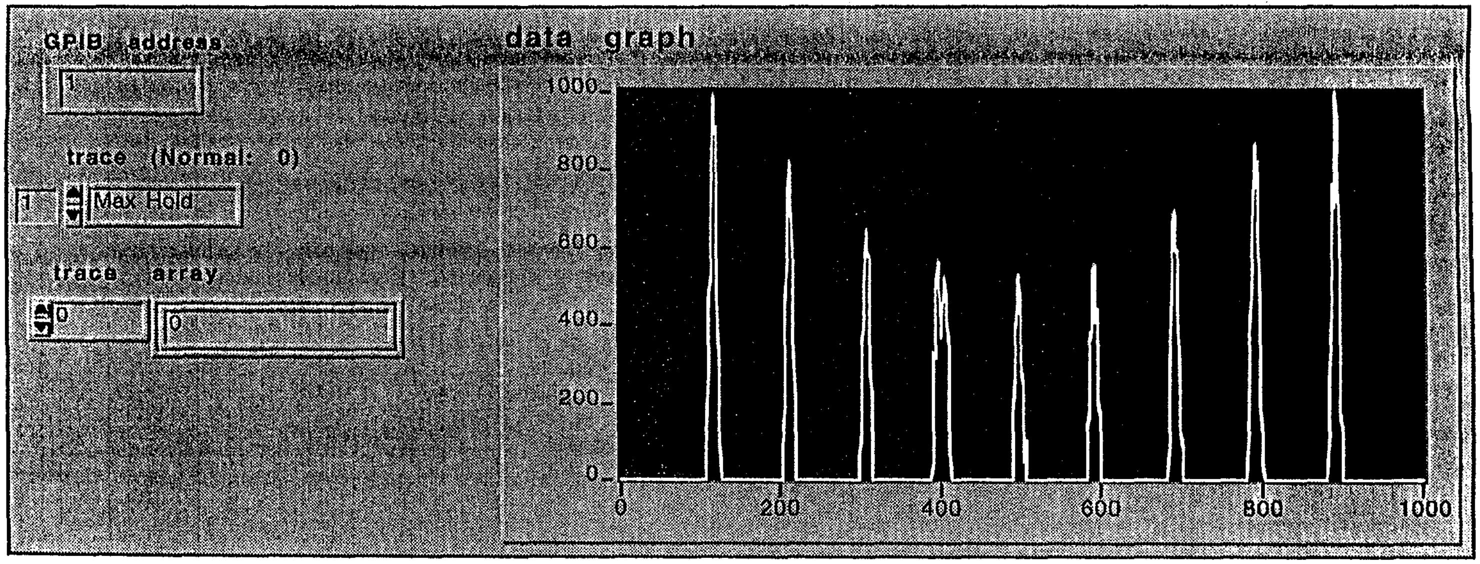

Figure 5. "Snap-shots" of resonances as the sample is moved along the axis for the minimum Q of the cavity.

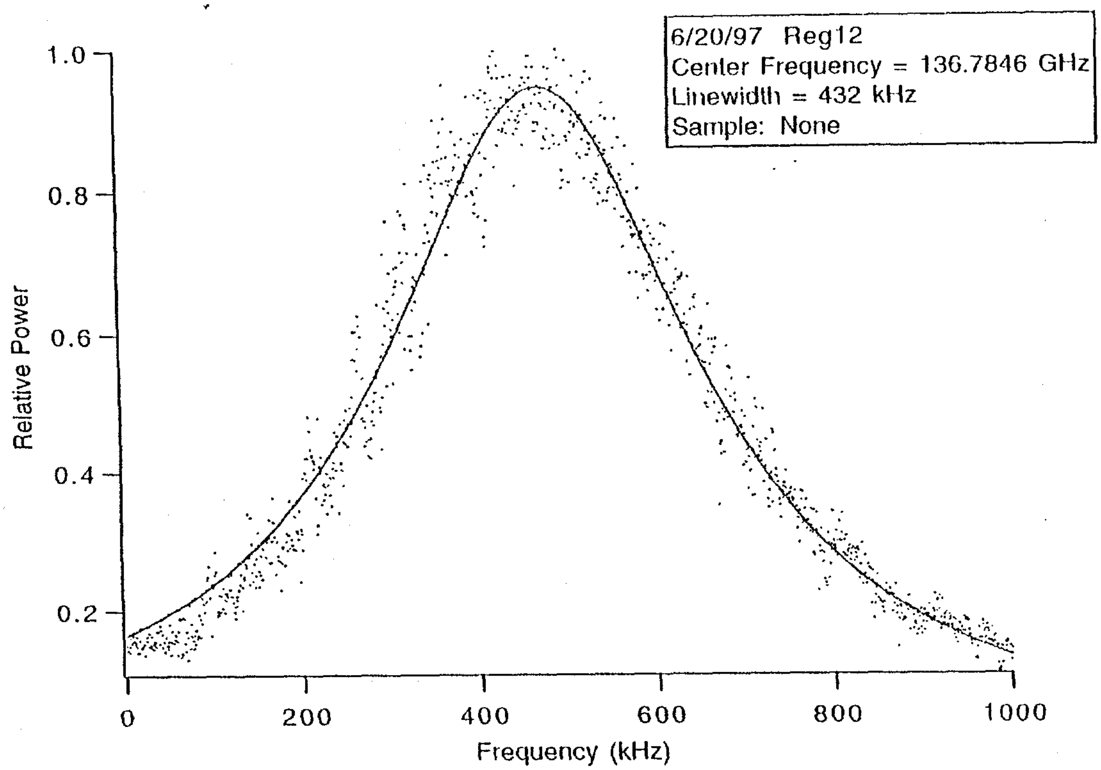

Figure 6. Fitted resonance curve of an empty resonator. The center frequency is 136.7846 GHz.

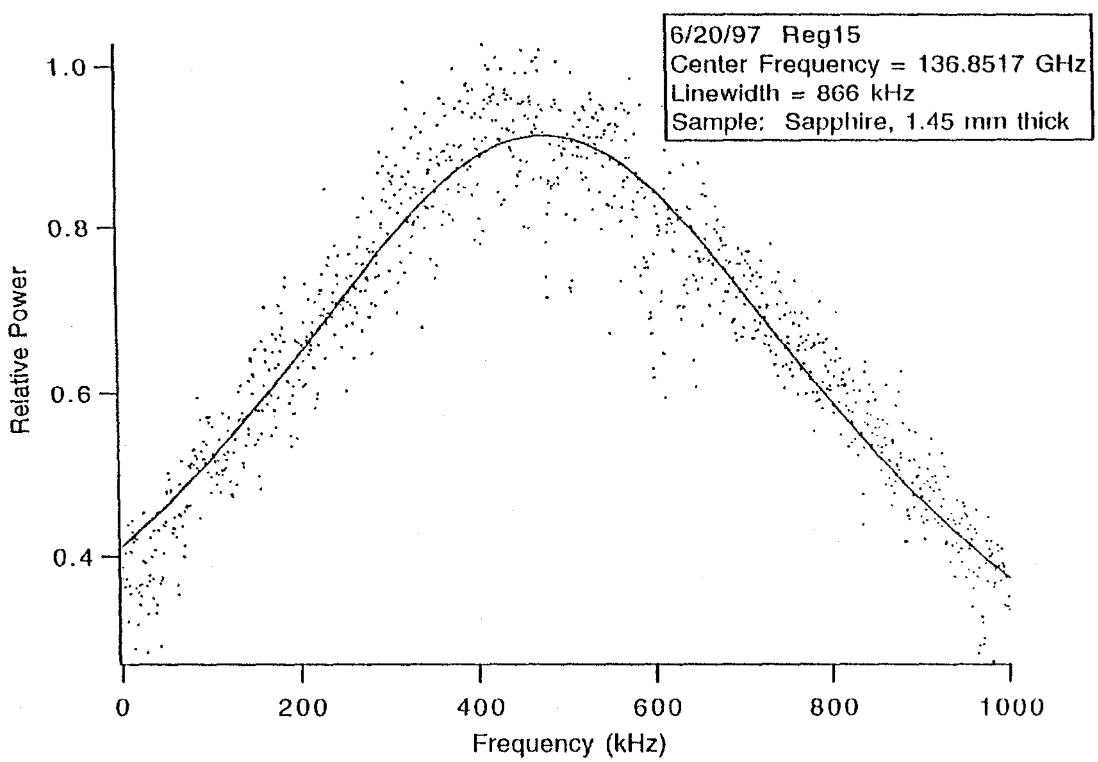

Figure 7. Fitted resonance curve of a resonator loaded with a 1.45 mm thick sapphire sample.

$$\tan\delta = (1.5 \pm 0.2) \times 10^{-4}$$

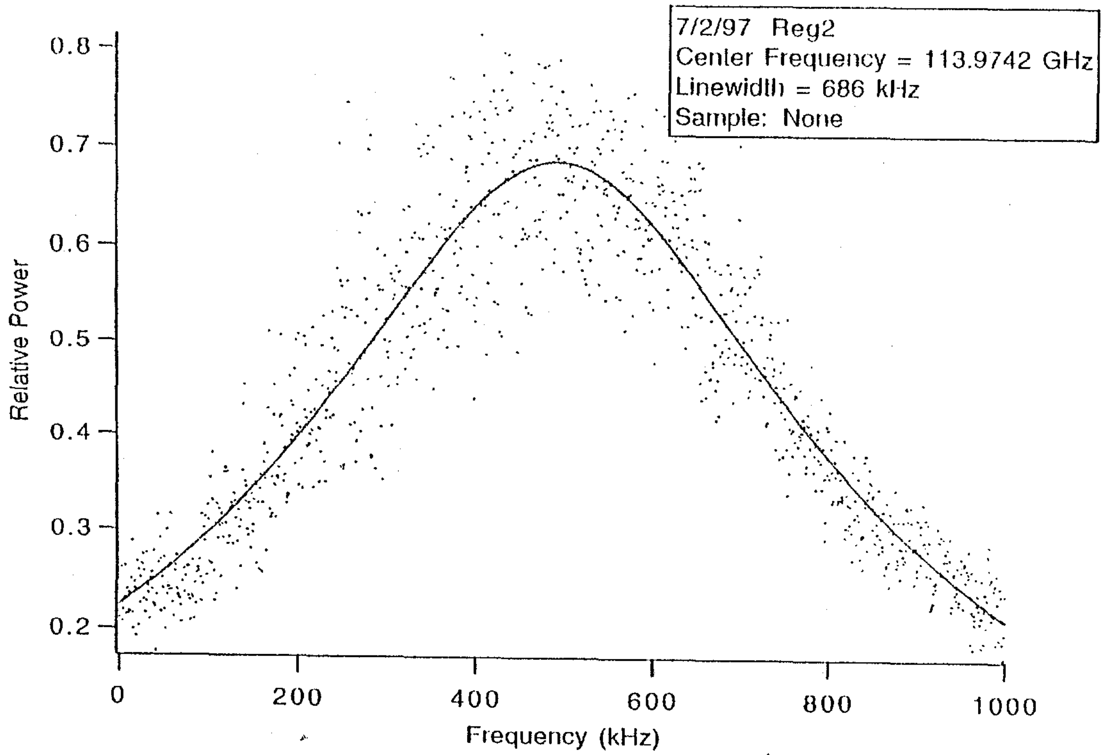

Figure 8. Fitted resonance curve of an empty resonator. The center frequency is 113.9742 GHz.

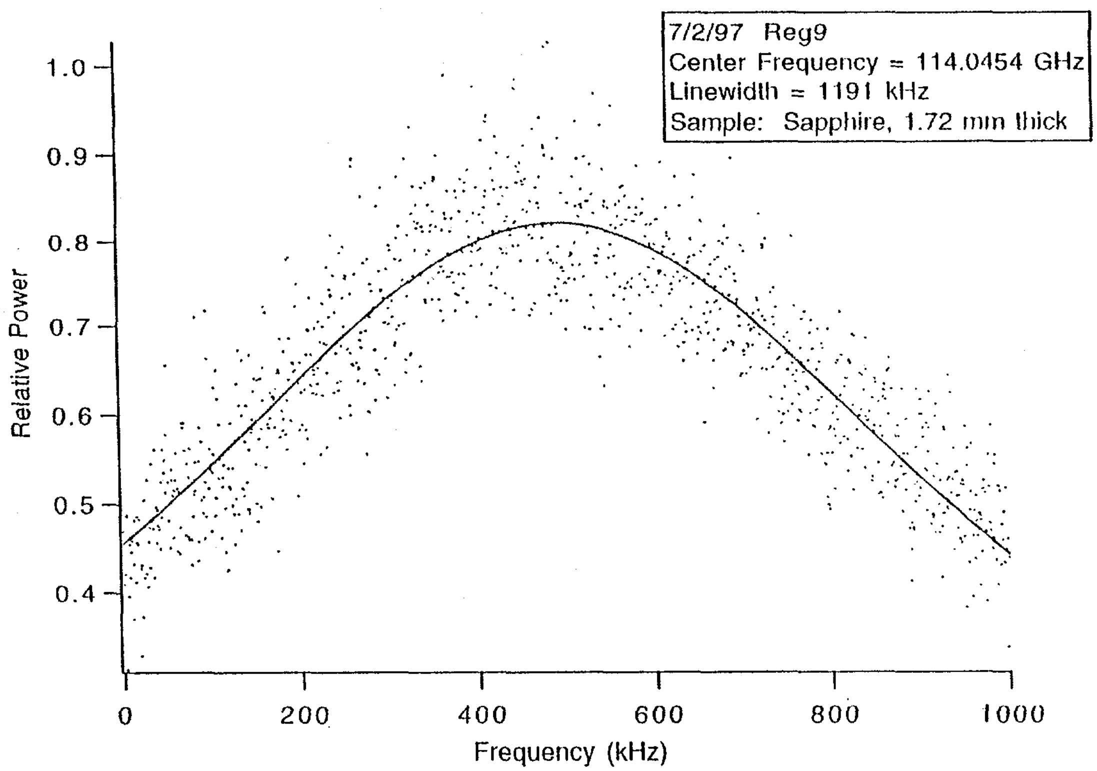

Figure 9. Fitted resonance curve of a resonator loaded with a 1.72 mm thick sapphire sample.

$$\tan\delta = (1.5 \pm 0.3) \times 10^{-4}$$