Measured and Computed Performance of a Microstrip Filter Composed of Semi-Insulating GaAs on a Fused Quartz Substrate

Peter H. Siegel, John E. Oswald, Robert J. Dengler, David M. Sheen, and Sami M. Ali

Abstract—**The performance of a microstrip hammerhead filter that has been fabricated on an electrically thin layer of semi-insulating GaAs backed by a fused quartz substrate is measured and computed. The filter is intended for applications involving ultra thin "lifted-off" or "etched-back" GaAs containing both active devices and passive microstrip circuitry backed by a much thicker mechanically rigid low-loss low-dielectric-constant substrate. The low pass characteristics of the hammerhead filter with the intermediate GaAs layer are compared with those of the same filter on quartz alone. Both the measured and computed data show a significant (≈ 10%) shift in the filter response curve when the thin GaAs layer is present.**

I. Introduction

There have been several recent papers [1]–[3] that discuss techniques for reducing the parasitic circuit capacitance of millimeter-wave planar air bridge type GaAs Schottky barrier diodes by completely etching away the semi-insulating material under the active region and transferring the device to a second carrier substrate that is better suited, both electrically and mechanically, for the intended high frequency application. This technique and a similar procedure presented in [4]–[5] are being explored as a means of producing a semi-integrated subharmonically pumped two diode mixer circuit for use at 640 GHz. For this application a planar antiparallel diode pair, formed using the process described in [1]–[3], is incorporated into the center of a pair of low pass microstrip filters formed on an insulating GaAs substrate. This filter isolates the signal and local oscillator ports on one side and separates the intermediate frequency from both the signal and local oscillator on the other. It is housed in a conducting rectangular box and is probe coupled to the input signal and local oscillator waveguides to form the complete mixer circuit. In order to increase the cutoff frequency for the dominant waveguide mode in the filter channel (so as to make the box as large as possible for ease of fabrication) as well as reduce the dielectric losses it is desirable to replace the GaAs substrate with one that is of lower dielectric constant and loss. In addition, the mechanical fragility of crystalline GaAs makes it a difficult material to handle when high-dimensional aspect ratios are required. An appealing substitute for millimeter and submillimeter wavelength applications is fused quartz which has an order of magnitude lower loss tangent, one third the dielectric constant and much more mechanical rigidity than GaAs. Using either of the two techniques described in [3] and [4] it should be possible to thin an entire GaAs wafer (containing many sets of diodes and filter elements) to a thickness on the order of 1–3 microns and then transfer the remaining active layer onto quartz. Individual mixer circuits would then be diced up after the transfer has taken place.

An interesting question that arises as a result of this procedure is the effect of the ultra thin GaAs layer on the filter characteristics. That is the subject of this short letter.

II. Measurements

To test the effect of the composite substrate we fabricated two $75X$ scale models of our 640 GHz harmonic separator filters, one with, and one without, the GaAs layer under the microstrip line and measured the response on an HP8510. The filter dimensions are shown in Fig. 1 and are derived from designs given in [6] and [7]. The passband cutoff frequency and stopband width were adjusted empirically by varying the lengths and separation of the hammerhead elements. The filter was intended for transmission of frequencies between ≈ 4.1 and 4.4 GHz (a 310-330 GHz local oscillator) and blockage of frequencies between ≈ 8.2 and 8.8 GHz (a 620-660 GHz RF signal)[1]. It is housed in a conducting cavity whose cross sectional dimensions (7.6 × 7.6 mm on the model or 100 × 100 μm at 640 GHz) were chosen to prevent the dominant waveguide mode from propagating in the filter stopband and to have as little effect on the signal waveguide it is coupling into as possible. The GaAs layer is 150 μm thick in the model and corresponds to a 2 μm thick substrate layer in the actual filter. For the measurements simulating the all quartz filters, the filter was photofabricated on Vicor, an inexpensive fused quartz material, using ≈ 13000 Å of evaporated aluminum to form the conducting lines. The GaAs/Quartz filter was modeled with a lapped and metalized GaAs wafer which, after photofabrication of the filter, was glued onto the Vicor carriers using a few dabs of cyanoacrylic adhesive. The measured transmission versus frequency for the two filters is shown in Fig. 2. The filter housing was 305 mm long with coax to microstrip launchers at each end. The long length

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[1] The increased stopband width of the hammerhead filter is the reason it was chosen over more conventional high/low impedance designs. This property is utilized in the intermediate frequency separator where a stopband from 4 to 9 GHz is required.

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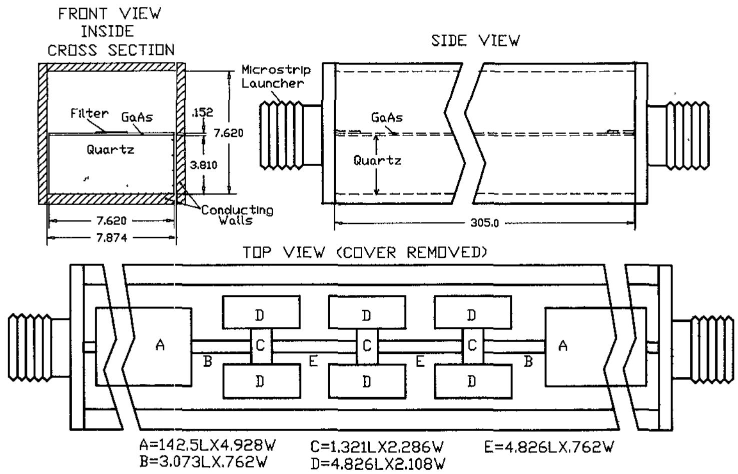

Fig. 1. Hammerhead filter whose response is shown in Figs. 2 and 3. Actual 640 GHz filter has five sections rather than three and has $B = 3.43L$ and $E = 5.33L$ with somewhat improved performance. All dimensions in millimeters.

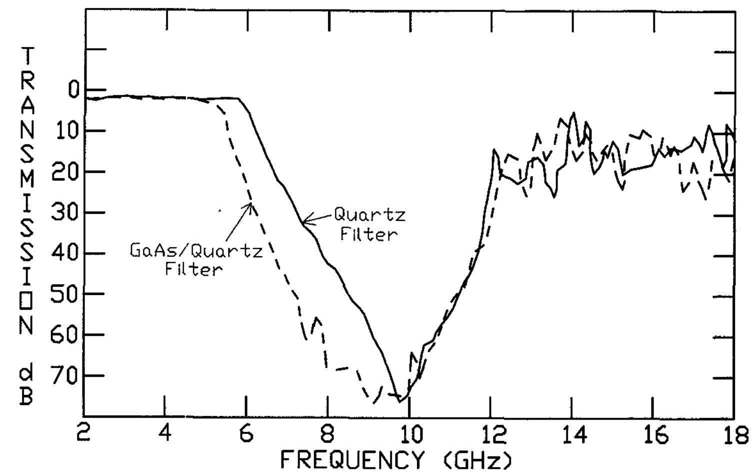

Fig. 2. Measured transmission response of three-section hammerhead filter of Fig. 1 with and without a 150 μm-thick layer of GaAs on top of the 3.81-mm thick quartz substrate.

($\approx$ 140 mm) of 50 Ω line on both sides of the filter was included to allow the microstrip launchers to be time gated out if desired (not in effect for the measurements presented here) and contributes to the excess loss in the passband. The rather large shift in cutoff frequency ($\approx$ 10% at the 3 dB points) is a bit surprising when one considers that the GaAs layer is only 0.007 wavelengths thick at 4 GHz but the change in relative dielectric constant implied by these results is consistent with the theoretical work of Yamashita [8, p. 532] who predicted and verified similar behavior on a double layer microstrip line composed of a very thin layer of silicon oxide on a silicon substrate. No noticeable difference in transmission loss was observed between the two filters.

III. Computed Results

In addition to the measurements, a three-dimensional finite difference time domain (FD–TD) program, written by two of the authors [9], was used to calculate the response of the filter both with and without the GaAs layer. The FD–TD method discretizes the entire structure and then simulates the propagation of a Gaussian pulse through the filter. The transmission coefficient over the entire frequency range is then obtained by Fourier transform of the transient response. As a compromise between computational speed and accuracy only five mesh points were used to model the dielectric substrate. With this discretization the GaAs layer would be five times too thick if modeled as one mesh spacing therefore a weighted average of the quartz and GaAs dielectric constants was used on the fifth mesh point. Even with this approximation the analysis does a fairly good job of predicting the filter response and shows the same relative shift in the transmission data when the GaAs layer is present as was measured on the network analyzer. The data is shown in Fig. 3.

Summary

The measured and computed response of a quartz hammerhead microstrip filter with and without a thin layer of GaAs under the conducting lines was reported. It was shown that even a very thin layer of high dielectric constant material can have a noticeable effect on the filter response. A finite difference time domain analysis of the filter agreed fairly well with the measured response and could be used for subsequent design. The filter has

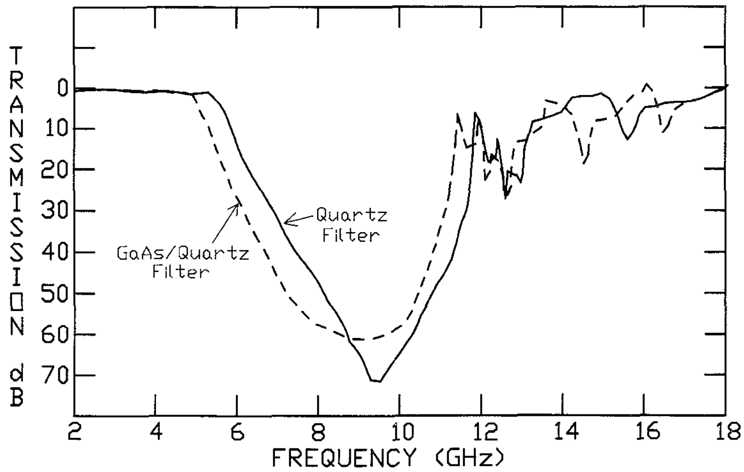

Fig. 3. Computed response of filter shown in Fig. 1 using FD-TD program described in [9] with and without GaAs layer.

an intended application as a harmonic separator in a hybrid-integrated submillimeter-wave subharmonically pumped mixer.

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