Optically-Controlled Tunable CPW Resonators

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Abstract

The use of a Schottky-biased, optically-controlled coplanar waveguide (CPW) in a microwave resonator is investigated. A prototype device consisting of a CPW atop a lightly doped GaAs epi-layer on a semi-insulating GaAs substrate has been fabricated and tested. By making use of Schottky-contacted metal electrodes to reduce loss and increase optical sensitivity, tunable resonance has been achieved, with resonator Q's of approximately 8.4 for resonance near 10 GHz, with a tuning range of about 125 MHz at an optical illumination power of only 34 mW/cm^2.

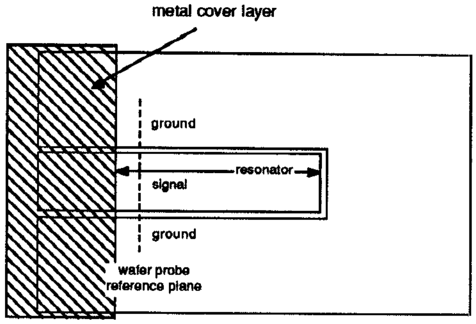
Introduction

Recently, several methods have been proposed for the construction of a distributed phase shifter using slow-wave propagation in a coplanar waveguide (CPW) on a layered semiconductor substrate [1]. By varying the phase constant of the transmission line, the phase delay the signal experiences while propagating through a fixed line-length varies, and thus phase shifting action takes place. We have recently demonstrated a phase shifter using coplanar waveguide, which utilizes a fixed Schottky bias with variable optical excitation. This device can exhibit extremely high optical sensitivity: 20^0 phase shift per centimeter line-length at 40 GHz requiring no more than 10^{-6} Watts of optical illumination power has been demonstrated [2]. In this paper we report the use of such an optically controlled transmission line to fabricate an optically tunable CPW resonator on a GaAs substrate.

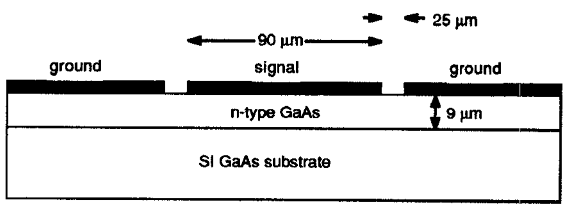
Device Fabrication

To implement the Schottky-bias/optical control approach, an MBE grown epitaxial GaAs layer on an SI GaAs substrate is used. The epitaxial layer is 9 µm thick with an n-type doping concentration in the low 10^{16} cm^{-3}. CPW devices were fabricated on this substrate using a chlorobenzene lift-off technique. The CPW electrodes consisted of evaporated chrome/silver/gold with a total thickness of about 1.2µm. The design of the resonant cavity is shown in Fig. 1. One end of the CPW is terminated by a gap between the center conductor and the ground plane, which produces a good rf open. To form the other end of the cavity the CPW is first coated with a dielectric overlayer. Metal is then evaporated over a section of the CPW. High frequency wafer probes (made by Design Technique) were then contacted to the section of the CPW left uncovered by metal. This produced a cavity that is approximately short-circuited at one end (the metal covered end) and open-circuited at the other (the gap end). The length of this section of line was approximately 3.5 mm.

The device is kept at a fixed reverse bias and is illuminated with an incandescent microscope illuminator. The spectral irradiance of this illuminator is typical of blackbody source, with wavelength integrated output power of 4.32mWatts.



(a)



(b)

Fig. 1 : (a) Top view and (b) crosssection of the optically controlled CPW resonator. The length of the resonator is approximately 3.5 mm.

Experimental Results

Measurements on this device were made with an HP8510B automatic network analyzer in conjunction with high frequency wafer probes over a frequency range of 0.045GHz to 40.0GHz. We used the illuminating intensity of 34.4 mW/cm^2, integrated over the full bandwidth of the source. Since light can be absorbed only through the gaps between the center conductor and the ground planes of the CPW, the device has an absorbing area of approximately 1.5×10^{-3} cm^2. Thus, the maximum absorbed optical power is about 51.6 μW. This represents an upper bound on the actual absorbed power, since any power at wavelengths longer than 867 nm is not absorbed by the GaAs.

The results of the measurements are summarized in fig.2 and fig.3. Fig. 2 and 3 show the resonant frequency and measured Q as a function of applied bias for illuminated and unilluminated cases respectively. In fig.2, it can be seen that the shift of resonant frequency with optical illumination decreases with increasing reverse bias, where fig. 3 shows that Q increases with increasing reverse bias. The maximum Q (11.8) is observed at +10V reverse bias, whereas the lowest Q (3.5) is observed under zero bias condition. The low Q at zero bias is because of the effect of undepleted epi-layer on the attenuation in the CPW. The optimum condition is found at -10V reverse bias, where the change of resonant frequency is 125 MHz (from 9.94 GHz to 9.815 GHz) and the corresponding measured Q is from 8.34 to 7.08.

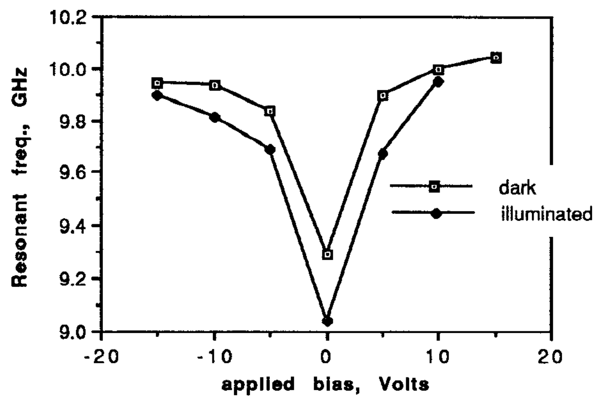


Fig. 2 : The resonant frequency as a function of applied bias for unilluminated and illuminated cases

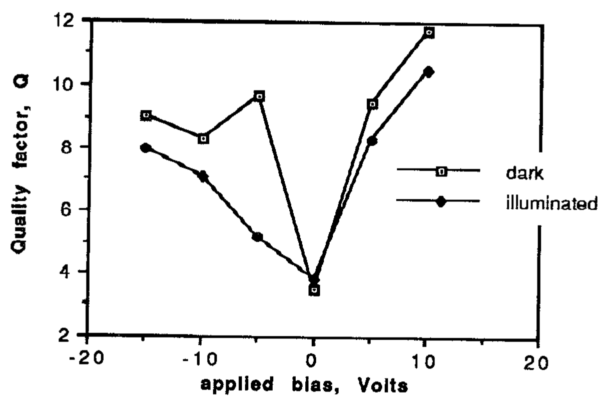


Fig. 3 : Measured quality factor, Q as a function of applied bias for unilluminated and illuminated cases

Conclusion

The basic idea of tunability of resonance point with low optical power is demonstrated in epi-layer of GaAs on the top of semi-insulating GaAs substrate. Though the tuning range (125 MHz) is not great, but the main limitation is the low Q's of the devices, which is not unusual with both high dielectric and conductor losses. The device structure has not been optimized for epitaxial layer thickness, doping concentration of the epi-layer, CPW dimensions, external coupling circuit or even the substrate material itself. Any simulation considering these variables would probably give a much better performance, but high loss probably will always be a constraint to good performance of devices like these.

References

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[2] P. Cheung, D. P. Neikirk, and T. Itoh, "A Schottky-Biased Optically-Controlled Coplanar Waveguide Phase Shifter," Electron. Lett. 25, Sept. 14, 1989, pp. 1301-1302.

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