AN OPTICALLY EXCITED MICROWAVE RING RESONATOR ON A GALLIUM ARSENIDE SUBSTRATE

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ABSTRACT

An optically excited ring resonator has been fabricated on a GaAs substrate. An optical signal, supplied by a laser diode modulated at microwave frequencies, was focused into a voltage biased resonator coupling gap to generate carriers from photoconductivity. Results from measurements of the optically generated microwave signal out of the ring resonator revealed resonant peaks at 3.48 GHz, 6.94 GHz, and 10.3 GHz with Q values of 53.5, 75.4, and 103.0, respectively.

INTRODUCTION

An optically excited ring resonator with a fundamental resonant frequency of 3.5 GHz has been fabricated on a GaAs substrate. The intermediate goal of the project was to modulate a laser diode at 3.5 GHz, 6.9 GHz, and 10.3 GHz and focus the optical signal into a voltage biased resonator gap to produce an optically generated microwave signal with the photoconduction effect. Optical techniques have not been used in the past due to the problem of modulating an optical carrier signal at frequencies above 30 GHz. Recently, a spectrally pure signal was produced at 35 GHz using an injection locked laser diode (1). In that experiment, two longitudinal modes a long cavity slave laser were locked to the FM sidebands of a master laser modulated at a frequency near 6 GHz. The eventual goal of this project is to use this injection locking technique to produce optically generated millimeter wave signals with a ring resonator on GaAs.

GaAs was chosen as the substrate for this device because it has generally good photoconductive properties and can be easily obtained in semi-insulating wafers with typical resistivity values greater than $10^7 \Omega \bullet$ cm. This allows for the fabrication of microwave circuits and photodetectors on the same substrate. In order to efficiently extract a modulated laser signal, it is necessary to use a low loss, high Q circuit. The circuit chosen was a ring resonator design because of its generally high Q value and the fact that it does not suffer from end effects. A GaAs substrate 15 mils thick was used to maximize the Q value at 10 GHz (2). In order to bias the resonator, a D.C. bias pad with an R.F. choke was designed into the circuit (figure 1). Applying a potential across the gap produces an electric field in the gap to sweep out the optically generated carriers. Modulating the intensity of the optical signal focused in the gap at microwave frequencies results in a modulation of the density of carriers in the gap at the same frequency. The resulting modulation in conductivity launches an electromagnetic wave in the ring resonator.

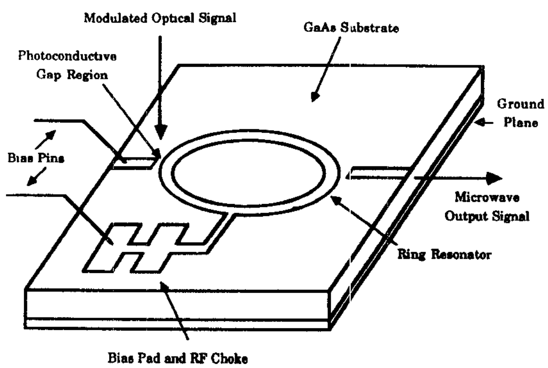

Fig.1 Illustration of the ring resonator circuit with the R.F. choke and bias pad.

FABRICATION PROCESS

A plate through process was used to fabricate the Au ring resonator on a GaAs substrate (3). The GaAs substrate was placed in a D.C. sputtering system where 400 Å of Ni followed by 1000 Å of Au were deposited for the ground plane. The ground plane was increased to 4 microns thick with gold electroplating. Afterwards, the substrate was placed in an electron beam evaporator and 750 Å of Au-Ge followed by 105 Å of Ni were evaporated onto the front of the wafer. Positive photoresist was spun onto the front of the wafer and the ring pattern was exposed and developed into the resist. The result was an insulting trench pattern of the ring resonator that served as a mask for the resonator during the plating process. After a hard bake at 135° C, the substrate was placed in a Au plating bath and 3.5 microns of Au was plated into the trench. The photoresist was then removed as was the thin layer of Au-Ge-Ni and the substrate was placed in a resistive strip heater and annealed for 2 minutes at 450° C to produce ohmic contact between the resonator and the substrate. This allowed for efficient extraction of the optically excited carriers from the voltage biased resonator gap. The substrate was then trimmed to the proper dimensions with a laser trimming system.

EXPERIMENTAL PROCEDURE

GaAs is a brittle substrate that can be easily damaged if not handled carefully. It was therefore necessary to build a substrate holder that would not damage or destroy the delicate circuits (4). This holder allowed for uncomplicated loading and unloading of delicate substrates as well as straightforward attachment to an optical x-y-z micropositioner for precise alignment with the modulated laser diode optical signal. Figure 2 shows the ring resonator circuit inserted in the substrate holder. The ring resonator microwave characteristics were tested in this holder with a model HP 8510A network analyzer. The S_{11} and S_{21} characteristics of the ring can be seen in figures 3 and 4, respectively. It can be seen from figure 3 that a decrease in the reflected signal occurs at the resonant frequencies of 3.5, 6.9, and 10.3 GHz. Other major decreases are seen at 2.3 and 5.5 GHz, although they are not a desired resonances. The S_{21} characteristic shows the resonant peaks at 3.475, 6.885, and 10.295, with output signals of -16.71 dB, -13.57 dB, and -13.5 dB, respectively. Again, additional maxima can be seen below the fundamental and second harmonic peaks. It is believed that these maxima are caused from mode splitting due to the R.F. choke and bias pad.

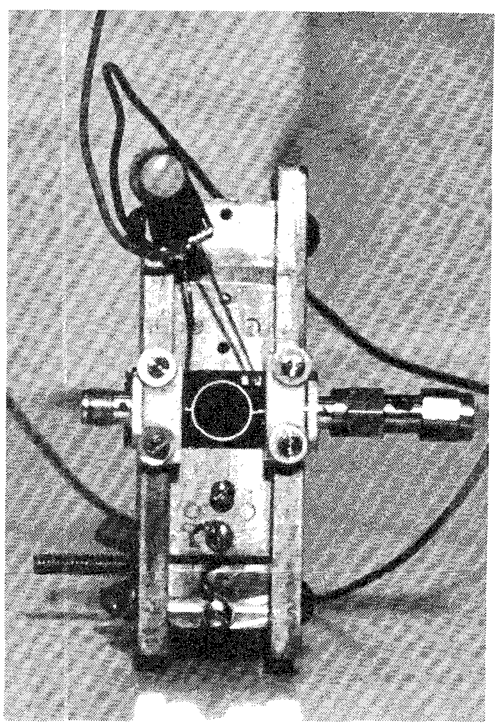

Fig.2 Ring resonator circuit inserted in the substrate holder.

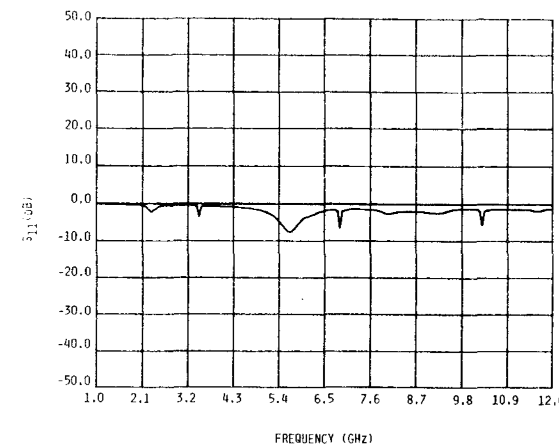

Fig.3 S_{11} microwave characteristic of the ring resonator measured with a HP 8510A network analyzer.

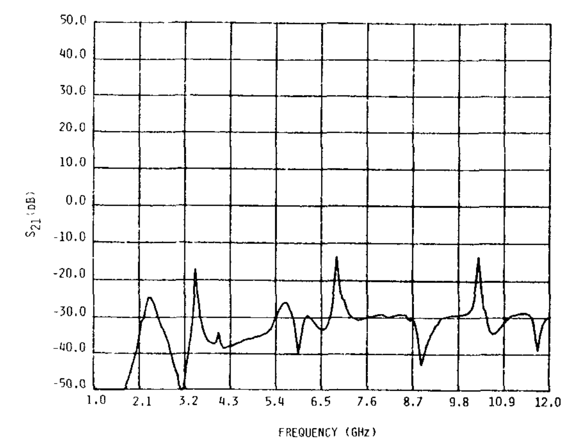

Fig.4 S_{21} microwave characteristic of the ring resonator measured with a HP 8510A network analyzer.

The optical response of the circuit was measured using the configuration in figure 5. The laser diode used was an Ortel model SL-1010. The laser diode was biased at 25 mA and the optical signal was sent through a laser collimator and focused into a resonator gap. The coupling gap was biased at voltages ranging between 1

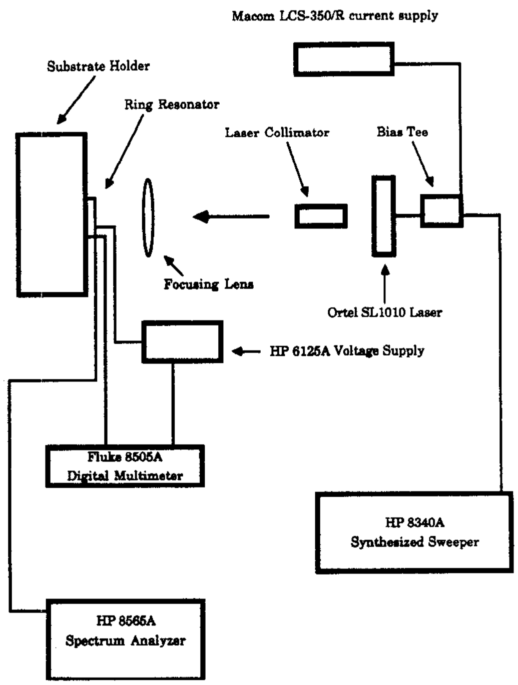

Fig.5 Equipment configuration used to measure the optically generated microwave signal from the ring resonator.

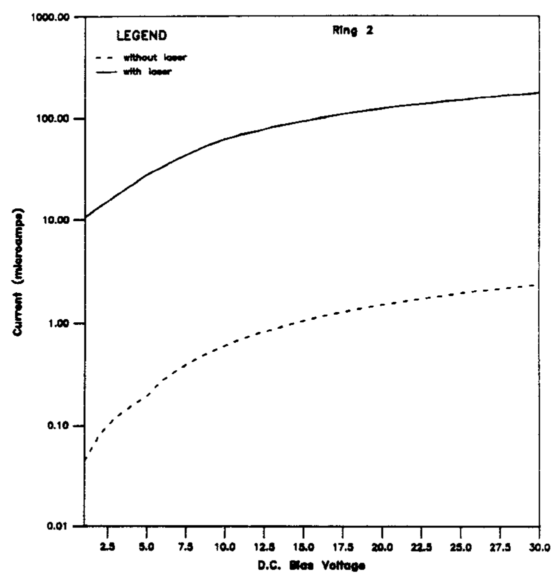

Fig.6 Characteristic curve of the leakage current and photocurrent from the ring resonator gap versus the bias voltage.

to 30 Volts and the leakage current and photocurrent were measured on a Fluke 8505A digital multimeter. The photocurrent increased at an average rate of 6 μA per volt and the leakage current increased at an average rate of 0.11 μA per volt. The characteristic curve of the leakage current and photocurrent versus the bias voltage can be seen in figure 6. The laser diode was then modulated at frequencies ranging from 4 to 11 GHz and the optical output power was measured on a HP prototype p-i-n diode with a rated 20 GHz bandwidth. From figure 7, it can be seen that the optical output power from the laser diode decreases quite rapidly after 7 GHz.

Early tests focusing the optical signal from a frequency modulated laser diode into a voltage biased resonator coupling gap revealed a maximum voltage at which no further microwave power could be gained. Measurements were taken at the first three resonant frequencies of the microwave output power for gap bias voltages ranging from 5 to 30 Volts. Figure 8 shows that a plateau is evident at which the output power levels off at a gap bias of 25 Volts. For this reason, the resonator gap was biased at 25 Volts for all tests conducted thereafter. It is believed the plateau occurs when full extraction of the optically generated carriers is realized. With the resonator gap biased at 25 Volts, the laser diode was modulated with an HP 8340A synthesized sweeper and incrementally changed from 2 GHz to 11 GHz in order to measure the output power of the ring resonator at various frequencies. The microwave output signal of the ring resonator was observed on an HP 8565A spectrum analyzer and the frequency characteristics can be seen in figure 7.

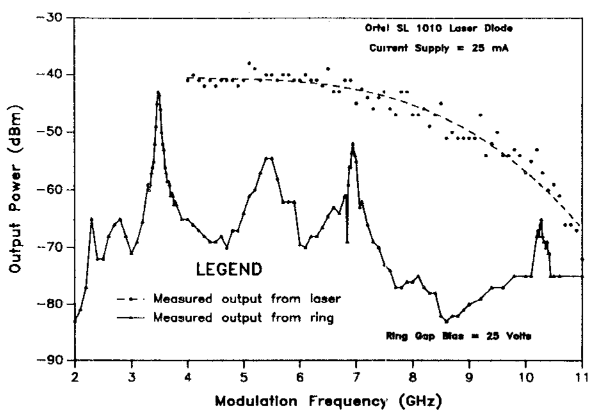

Fig.7 Ortel SL-1010 laser diode frequency response at a bias of 25 mA compared to the frequency response of the optically excited microwave signal from the ring resonator circuit.

RESULTS

The results of the measurements of the microwave characteristics of the unmodulated ring resonator as determined by the HP 8510A network analyzer revealed resonant peaks at 3.475 GHz, 6.885 GHz, and 10.295 GHz with Q values of 49.3, 81.5, 121.8, respectively (figure 4). The optically excited results of the resonator taken with a frequency modulated laser diode revealed resonant peaks at 3.48 GHz, 6.94 GHz, and 10.3 GHz with Q values of 53.5, 75.4, and 103.0, respectively (figure 7). Maxima were again observed near 2.3 and 5.5 GHz, although the output power in both cases was lower than the fundamental and second harmonic resonances. These maxima are believed to be the result of mode splitting caused from irregularities produced by the R.F. choke and bias pad. The output power of the of the optically driven ring resonator was measured to be -43 dBm at 3.48 GHz, -52 dBm at 6.94 GHz, and -65 dBm at 10.3 GHz. The decrease in output power of the resonator with increasing frequency closely follows the decrease in output power of the modulated laser diode with increasing frequency. It is believed that the combined effects from the decrease in optical power from the laser diode and the decrease in optical sensitivity of the photoconductor with increasing frequency are the cause of the decreases in output power of the ring resonator at subsequent resonant peaks. Although the output power of the ring resonator device is low, it successfully demonstrates the ability to generate microwave signals using optical techniques.

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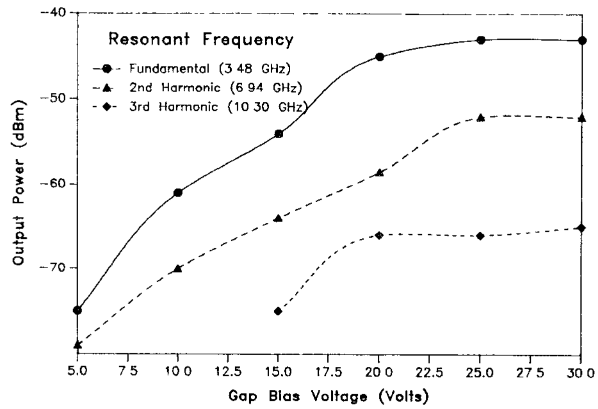

Fig.8 Microwave output power from the ring resonator device at the first three resonances versus the coupling gap bias voltage.

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