RESISTIVE MIXING AND PARAMETRIC UP-CONVERSION OF MICROWAVE OPTOELECTRONIC SIGNALS IN A MICROSTRIP RING RESONATOR

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ABSTRACT

A novel microwave optoelectronic mixer is fabricated on semi-insulating GaAs by monolithically integrating Schottky diode photodetectors into a microstrip ring resonator. Resistive mixing occurs when the conductance of the detector is modulated, and parametric amplification occurs when the capacitive reactance of the detector is modulated. The results should impact future fiber-optic communication systems.

I. INTRODUCTION

Recent advances in optoelectronic technology have rendered multi-gigahertz bandwidth fiberoptic systems practical [1]. The excellent transmission properties of optical fibers and the immunity of lightwaves to electromagnetic interference, coupled with the availability of high speed laser diodes, have provided a major thrust to research in the field of microwave optoelectronics. Hence, integration of high frequency optical and electronic components in the same chip is currently under intense investigation [2]. This research involves the integration of a Schottky diode photodetector into a microstrip ring resonator. Reported herein is the operation and performance of the circuit for resistive mixing at baseband and for parametric up-conversion.

II. CIRCUIT DESCRIPTION

The layout of the circuit is illustrated in Figure 1. Since the Q-factor of the ring resonator is better than that of the linear resonator, the ring was chosen for experiments. The circuit is fabricated on semi-insulating GaAs. The substrate thickness of 0.375 mm (15 mil) is chosen to maximize the resonator Q-factor near 10 GHz [3].

The measured $|S_{21}|$ vs frequency characteristics of the circuit are shown in Figure 2. Resonances were measured to occur at 3.467 GHz, 7.18 GHz and 10.4 GHz. Corresponding loaded Q-factors are 45, 58 and 74. The circuit entails bias lines to facilitate biasing of the detector diode; bias is applied via low pass filters whose cutoff frequency is near 2 GHz. Since this frequency is lower than the ring resonator's fundamental resonant frequency, the intrinsic fields of the resonator are not appreciably perturbed as verified by application of the distributed transmission line model to the circuit [4]. Two $4-\mu m$ slits are introduced at diametrically opposite locations of the ring for optical excitation. These slits are designed to be collinear with the feed lines so that mode configuration of this resonator is identical to that of the completely closed ring [5]. The dimensions of the coupling gaps between the feed lines and the resonator were chosen to be 30 μm and 100 μm, respectively. In this configuration, the microwave LO excitation is applied via the more loosley coupled 100μm gap and the output signal is extracted across the 30μm gap. It is thus ensured that whereas the LO signal is loosely coupled into the resonator, extraction of the output signal is more efficient due to the tighter coupling associated with the 30μm gap.

To fabricate the circuit, the pattern is delineated photolithographically in a 1000 Å thick Au-Ge-Ni layer. This is followed by electroplating of Au to a thickness of about 3.2 μm. The N_i and Au-Ge are then removed from the unpatterned areas by etching, and the substrate is annealed with a resistive strip heated at 240°C to form Schottky contacts. Annealing at temperatures about 300°C was found to produce ohmic contacts. When DC bias is applied at the bias pads, the slit region of the circuit acts like two diodes connected back to back. When the circuit is operated as a resistive mixer, the conductance of these diodes is modulated, and the difference frequency at baseband is extracted from the bias pad of the circuit. When operated as a parametric amplifier, the capacitive reactance of the detector diodes is modulated and sum and difference frequencies in the microwave band are extracted from the feed line of the circuit.

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IV. CIRCUIT PERFORMANCE

The test setup is illustrated in Figure 3. When a modulated optical signal from a laser diode is applied to one of the slits of the ring resonator, an RF voltage is induced. By virture of the ring's moderately high Q-factor, the manifestation of this phenomenon is enhanced when the circumference of the ring becomes an integral multiple of the wavelength corresponding to the RF signals. The RF signal is the modulating signal to the optical carrier. When a larger amplitude local oscillator (LO) microwave signal is applied to the feed line of the circuit, this signal is mixed with the RF optical signal if both the LO and RF frequencies are at the ring's resonance; the down converted intermediate frequency (IF) difference signal is obtained from the bias pad of the circuit. When the IF signal at baseband is extracted from the bias pad, the circuit is said to be operated in the "resistive mixing" mode as the circuit operation in this case involves the modulation of the conductance of the detector doides. For operation in this mode, the RF and LO ports are mutually isolated and the low pass filter automatically suppresses the image frequency.

The Ortel SL 1010 laser diode, with an operating wavelength of 0.84 μm and a threshold current of 6.6 mA is biased at 9 mA and operated with an input modulated power of − 14 dBm at 3.467 GHz. When a LO signal close to the fundamental resonance of the ring is applied at the feed line, the spectrum of the IF signal obtained at the bias pad is shown in Figure 4. If either one of the RF or LO frequencies is tuned away from resonance, the IF signal strength at the bias pad gradually decreases. This is illustrated in Figure 5. As can be seen, the peak of the IF signal output occurs when the LO is close to the ring's resonance; when tuned out of resonance, the strength goes down; similar effects were observed in varying the RF.

In the "parametric mode," sum and difference frequencies in the microwave band are extracted from the feed line of the circuit. For operation in this mode, the ring should resonate at the RF, LO and IF frequencies. When the LO pump frequency is at the ring's second resonance, and the RF optical signal at the first, the spectrum of the up-converted IF signal at the ring's third resonance is shown in Figure 6. A parametric amplification gain of 3dB was observed.

V. CONCLUSIONS

A novel microwave optoelectronic mixer has been monolithically fabricated on semi-insulaing GaAs. The circuit can be used for both resistive mixing at baseband and parametric amplification in the microwave band. The mixer shows very good potential for application in wideband fiber optic systems.

VI. ACKNOWLEDGEMENTS

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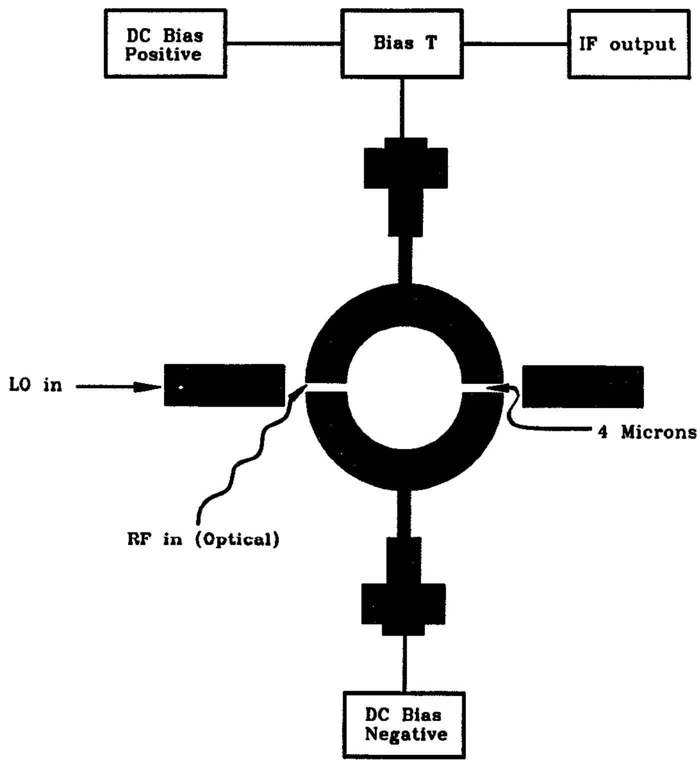

Fig 1 Layout of ring resonator circuit

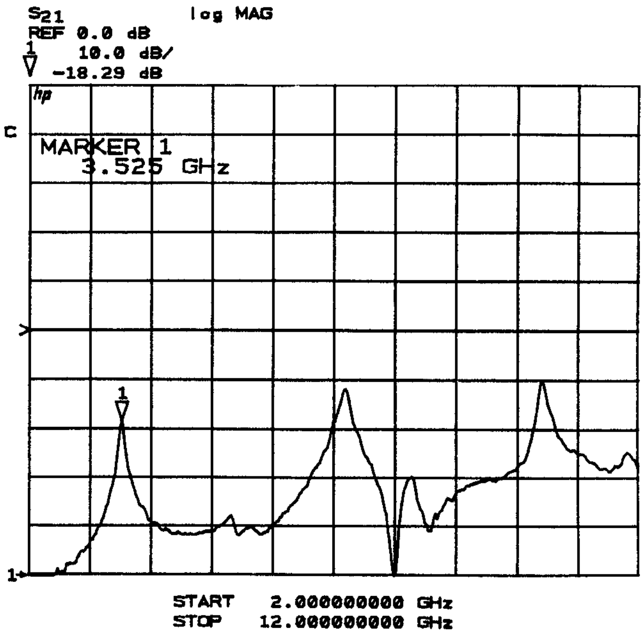

Fig 2 $|S_{21}|$ vs frequency of the circuit

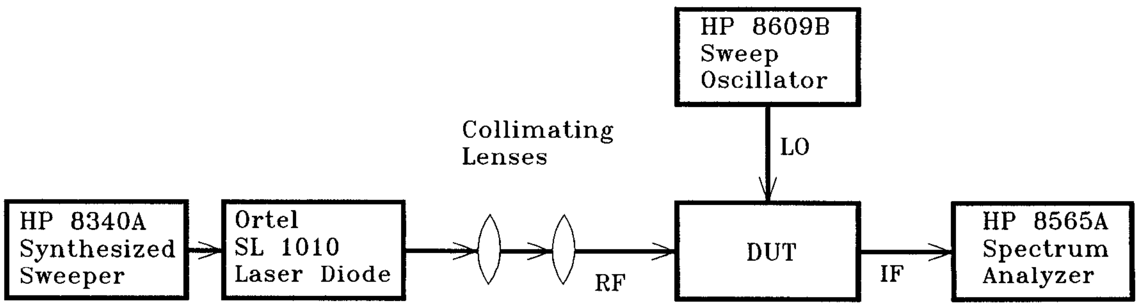

Fig 3 Experimental test setup

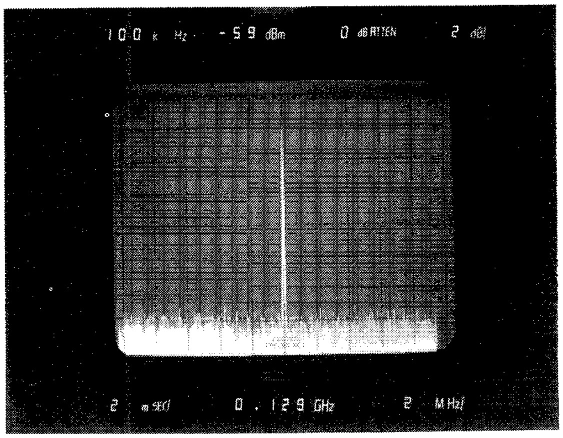

Fig 4 Spectrum of IF output at bias pad,
RF = 3.467 GHz, LO = 3.596 GHz,
IF = 0.129 GHz

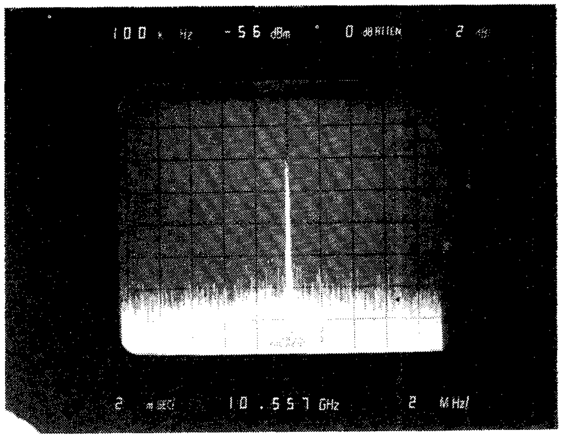

Fig 6 Spectrum of IF output at feed line,
RF = 7.07 GHz, LO = 3.487 GHz,
IF = 10.557 GHz

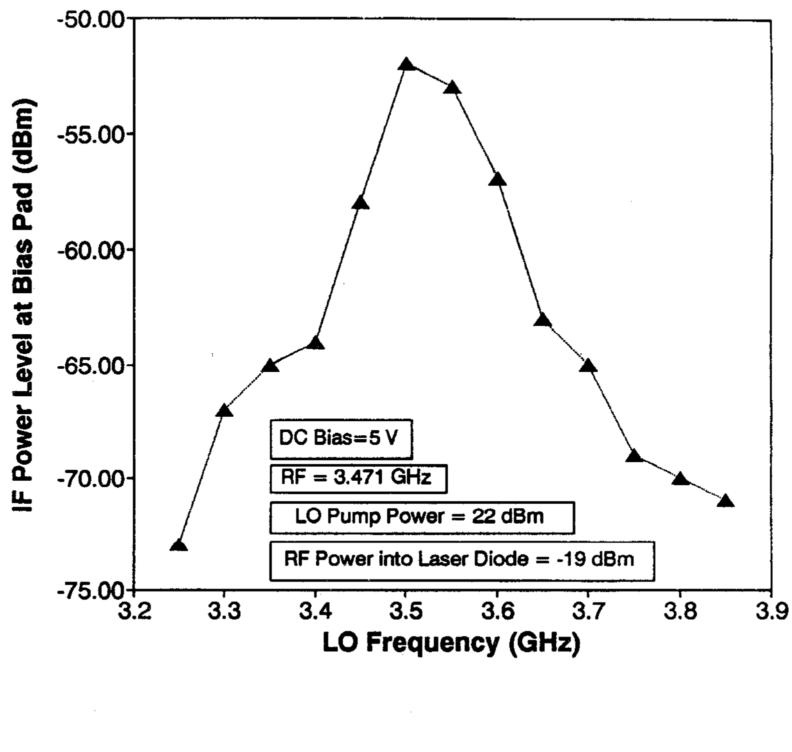

Fig 5 IF power at bias pad vs LO frequency