MONOLITHIC IMPATT MILLIMETER-WAVE OSCILLATOR STABILIZED BY OPEN-CAVITY RESONATOR

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Abstract: A monolithic IMPATT oscillator operating in the 50 Ghz region has been controlled in frequency in an open microwave resonator. Also, the noise spectrum of the oscillator in a closed quasi-optical cavity showed substantial improvement when compared to oscillation in free-space. These results show that monolithic circuits are compatible with open resonator techniques, and can lead to improved monolithic oscillator stability.

INTRODUCTION

Although IMPATT diodes are the source of choice for millimeter wave solid-state transmitter applications because of their unmatched power performance and efficiency, mass production of multiple device IMPATT sources has been hampered by the need for tedious and exacting manual assembly of the coaxial or cylindrical waveguide power-combining cavities needed. Recent progress in monolithic integration of IMPATT diodes [1] has shown that useful power levels can be obtained from monolithic devices built into microstrip oscillator circuits. However, the highest power obtainable from a single integrated diode is limited by fundamental heat-dissipation problems. Mutually coupled phased arrays of two-diode oscillators [1] are one solution to this problem. We report in this paper some initial steps toward a second approach to the problem of combining the power of integrated millimeter-wave IMPATT oscillators: operation in a quasi-optical Fabry-Perot resonator. With this technique, we have demonstrated that an open resonator mode is capable of determining the oscillation frequency of a monolithic IMPATT oscillator, and that in an enclosed quasi-optical cavity, the spectral characteristics of the monolithic IMPATT oscillator are substantially improved. The very high unloaded Q of such resonators can thus improve the performance and flexibility of monolithic IMPATT oscillators and may lead to efficient power-combining.

CIRCUIT FABRICATION

The IMPATT structure used in this study was of the flat-profile, double-drift type, and was grown by MOCVD on semi-insulating substrates. The doping concentrations and thicknesses of drift regions were typically $2X10^{17}$ cm^{-3} and 0.25 μ m, respectively. Each active circuit contained two 5 μm diameter IMPATT diodes placed close to the ends of the microstrip resonator circuit element. The n^+ contact of the diode was connected to the resonator while the p^+ contact was connected to ground by the use of an air bridge and via ground contacts. The location of the IMPATT diodes and the dimensions of the resonator circuit were chosen for operation in the 50-60 Ghz range, and the circuit layout resembled that in Ref. [1].

OSCILLATOR IN OPEN CAVITY RESONATOR

The open cavity resonator is capable of unloaded Q values of 10^5 in the millimeter-wave range, and a recent study [2] has shown how such high-Q resonances can be used to advantage in microstrip circuits. Stabilization and power combining of microstrip oscillators in an open-cavity resonator has been demonstrated at X-band [3]. In the work reported here, the same basic principle is extended to 50-60 GHz region. Fig. 1 shows the experimental setup used. The IMPATT chip with its two-diode microstrip oscillator circuit was mounted on the surface of a flat brass reflector and biased with a bond wire leading to a coaxial cable, as in [1]. A spherical concave copper reflector having a diameter of 5.1 cm. and a radius of curvature of 4.83 cm. was mounted opposite the chip. Power was coupled out of the cavity by a very small coaxial loop at the center of the spherical mirror. For an inter-reflector distance D less than the radius of curvature, optically stable TEM_{00q} modes exist between the two reflectors and can couple to the currents in the microstrip resonator of the monolithic IMPATT oscillator. Fig. 2 is a plot of frequency versus inter-reflector distance D for the TEM_{005} mode and the experimentally measured oscillator frequency. The free-space oscillation frequency was 51.772 GHz. When the physical reflector distance is increased by a constant (0.1101 cm.) to account for the chip's loading of the resonator, agreement is seen to be reasonably good. Maximum output power for this mode was -15.3 dBm, but the coupling loop used was not optimized for best power output. About -8 dBm was obtainable from the circuit with an open waveguide placed directly above the chip, without reflectors.

OSCILLATOR IN CLOSED QUASI-OPTICAL RESONATOR

The same run of monolithic IMPATT oscillators was used in this experiment, which was an investigation of the spectral characteristics of the oscillator in a high-Q cavity. Referring again to Fig. 1, the setup used is basically the same except that a brass can was manufactured to enclose the cavity, stabilize it mechanically, and allow the inter-reflector distance to be varied from 2.5 cm to 4.8 cm. Also, the output coupling mechanism used was a slot coupling to waveguide at the center of the spherical mirror. The closed cavity is highly overmoded, but the swept response of the cavity in the 50-60 GHz range was measured with the result that unwanted modes were generally not excited strongly and could be damped even further by lining the brass can with ferrite absorber. The spectrum of a monolithic IMPATT oscillator operating at 56.031 GHz was first measured with a waveguide placed within 1 mm of the chip, and with the position of the chip with respect to the waveguide optimized with a planar positioner. The plot is shown in Fig. 3. Then the oscillator was placed within the cavity and the inter-reflector distance was varied so that the desired TEM_{00q} mode optimized the power and the spectral characteristics. The

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adjustment we found was stable and repeatable with respect to bias changes and turn-on transients. The plot of the oscillator operating at 56.097 GHz in the cavity is shown in Fig. 4. Our calculations indicate the oscillator was operating in the $TEM_{0,0,14}$ mode of the cavity. A comparison of Fig. 3 and Fig. 4 shows that there is considerable improvement in the noise spectrum of the monolithic IMPATT oscillator when radiating in the cavity, without appreciable loss of power. Although the power of these particular IMPATT oscillators was on the order of 1 mW, the chips were not designed for maximum power. However, similar monolithic IMPATT oscillators have been demonstrated at higher output power in [1].

CONCLUSION

To the best of our knowledge, this work represents the first successful use of a millimeter-wave quasi-optical cavity in two respects: first, as the frequency-determining element of a monolithic millimeter-wave oscillator; and second, as a means of coupling the monolithic oscillator to a high-Q cavity mode for improved spectral response.The resulting oscillator is simple and has low phase noise. Although the output power was not high and only a single oscillator was used in both experiments, we have shown that a monolithic circuit can be operated on the reflector of an open resonator without seriously degrading the quality factor. Thus, millimeter-wave power combining using the desired cavity mode as the dominant coupling mechanism among individual oscillators should be feasible. The possibility of highly efficient, coherent power combining will be investigated using the same basic approach outlined here.

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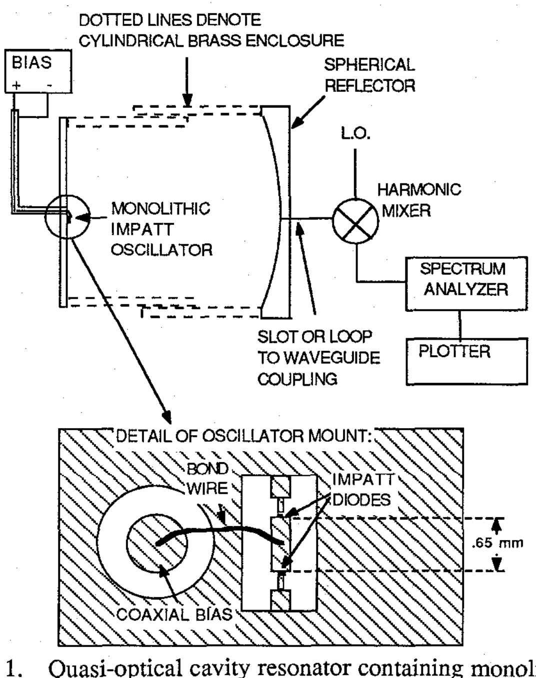

FIG. 1. Quasi-optical cavity resonator containing monolithic IMPATT oscillator chip.

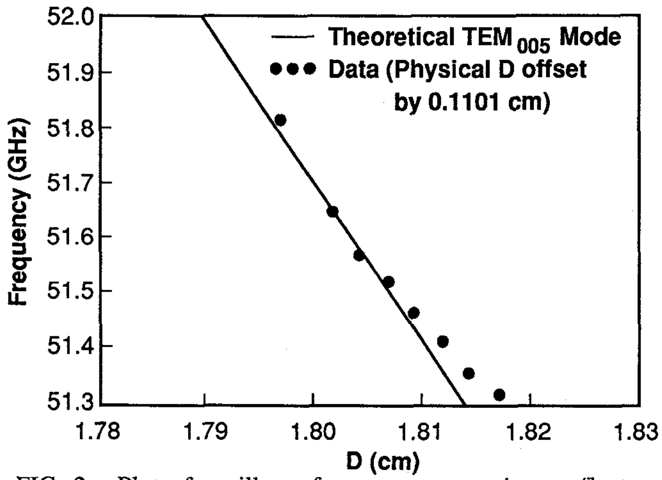

FIG. 2. Plot of oscillator frequency versus inter-reflector distance D (experimental data's D offset 0.1101 cm from physical measurement).

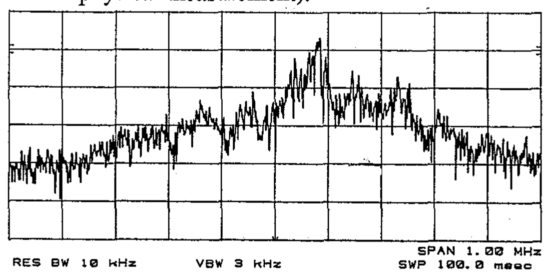

FIG. 3. Monolithic IMPATT oscillator spectral response at f_0=56.031 Ghz while operating directly into waveguide.

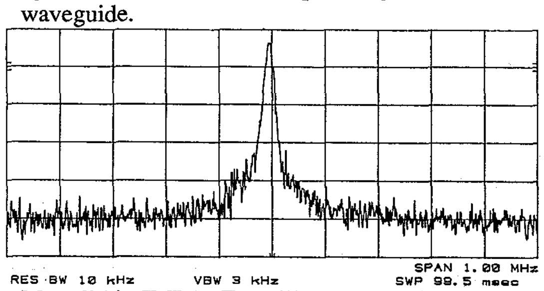

FIG. 4. Monolithic IMPATT oscillator spectral response at f_0=56.097 Ghz while operating in the closed quasi-optical cavity.

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