B.S.T.J. BRIEF

A Low-Noise Metal-Semiconductor-Metal (MSM) Microwave Oscillator

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I. INTRODUCTION

Low-noise microwave CW oscillations have been obtained from metal-semiconductor-metal (MSM) structures made from a 10-μm thin slice of silicon sandwiched between two PtSi Schottky barrier contacts. Microwave CW power up to 50 mW has been obtained at 5 GHz with efficiency up to 1.8 percent. The FM noise measure 1 MHz from the carrier is 22.8 dB which is considerably lower than that of a silicon avalanche oscillator. The mechanisms responsible for the microwave oscillation are (*i*) the exponential increase of the local carrier population due to injection of minority carriers at the forward-biased contact and (*ii*) the transit-time delay of injected carriers traversing the depletion region. By optimizing material and device parameters, it is believed that higher efficiency and higher power microwave oscillations can be obtained from the MSM and its related structures with the inherent low-noise characteristics.

II. DEVICE FABRICATION

Single-crystal n-type silicon wafers with 11Ω-cm resistivity (4×10^{14} cm^{-3} doping), ⟨111⟩ oriented, and with a dislocation density less than 100/cm^2 were Syton polished on both sides to a final thickness of 10 ± 2 μm. Platinum of 500 Å thickness was sputtered onto both sides of the wafer and was sintered to form approximately 1000 Å PtSi on both sides. Chromium of 300 Å was deposited on one side; this was followed by a 3000 Å layer of Au evaporation. The same depositions were then made on the other side. A standard photolithographic method was used to define circular patterns of gold dots with areas of 5×10^{-4} cm^2. The devices were separated by etching and were mounted onto V-type microwave packages.

III. DC CHARACTERISTICS

A schematic diagram of an MSM structure is shown in Fig. 1a. The band diagram at thermal equilibrium is shown in Fig. 1b for an n-type semiconductor where ϕ_{n1} and ϕ_{n2} are the barrier heights for the two metal-semiconductor contacts respectively. For the PtSi-Si-PtSi structure mentioned previously, $\phi_{n1} = \phi_{n2} = 0.85$ eV. Figure 1c shows the energy band diagram when a voltage is applied. We have electron current from the reverse-biased contact and hole current from the forward-biased contact.

The measured I-V characteristics at 300°K and 77°K of a representative device is shown in Fig. 2. The rapid increase in terminal current with applied voltage (above 30 volts) is caused by thermionic

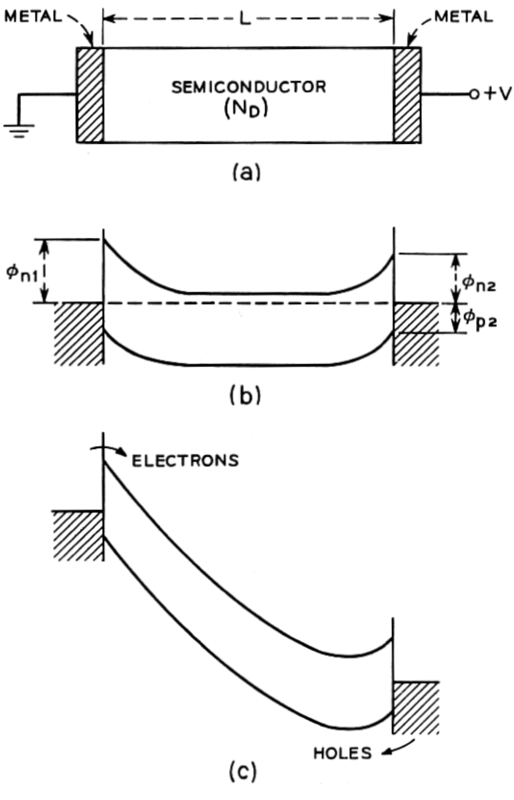

Fig. 1—(a) Schematic diagram of a metal-semiconductor-metal (MSM) structure. (b) Energy band diagram of an MSM structure in thermal equilibrium. (c) Energy band diagram of an MSM structure under biasing condition.

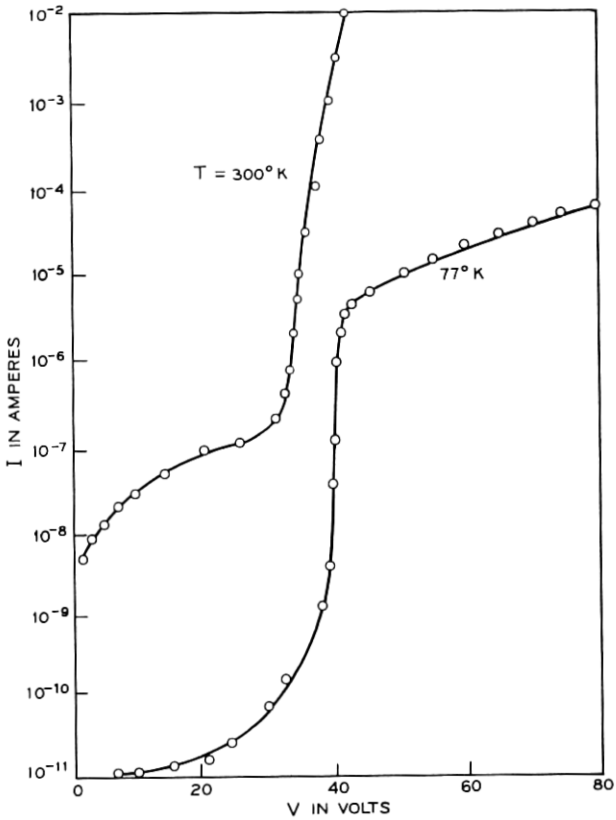

Fig. 2—Measured current vs voltage of a silicon MSM structure (PtSi-Si-PtSi) at two temperatures. The device parameters are $L = 10\ \mu m$, $N_D = 4 \times 10^{14}$ cm^{-3}, $\phi_{n1} = \phi_{n2} = 0.85$ eV, and with an area of 5×10^{-4} cm^2.

hole injection into the semiconductor as the depletion layer of the reverse-biased contact reaches through the entire device thickness. This critical voltage is approximately given by $qNL^2/2\epsilon_s$, where N is the doping concentration, L the semiconductor thickness, and ϵ_s the dielectric permittivity.[1] The current increase is not due to avalanche multiplication as is apparent from the magnitude of the critical voltage and its negative temperature coefficient. At 77°K, the rapid increase is terminated at a current of about 10^{-5} amps. This saturated current is expected from the thermionic emission theory of hole injection[1] from the forward-biased contact with a hole barrier height (ϕ_{p2}) of about 0.15 eV.

IV. MICROWAVE PERFORMANCE

CW microwave performance of the MSM devices was measured in a coaxial Impatt circuit described by D. E. Iglesias.[2] Microwave power was obtainable over the entire C band of 4–8 GHz. The maximum power observed was 50 mW at 4.9 GHz. The maximum efficiency approached 1.8 percent. Figure 3 shows some of the measured microwave power versus current with frequency of operation indicated on each curve for three typical devices tested. The voltage indicated in parenthesis labeling each curve is the average bias voltage at the diode while oscillating. Because of the symmetry of the structure, it could be operated with either polarity of bias voltage, and similar results were obtained.

The highest-power unit was tested for FM noise when tuned to a frequency of 4.88 GHz. The FM single-sideband noise measure 1 MHz from the carrier frequency was found to be 22.8 dB at 7 mA bias

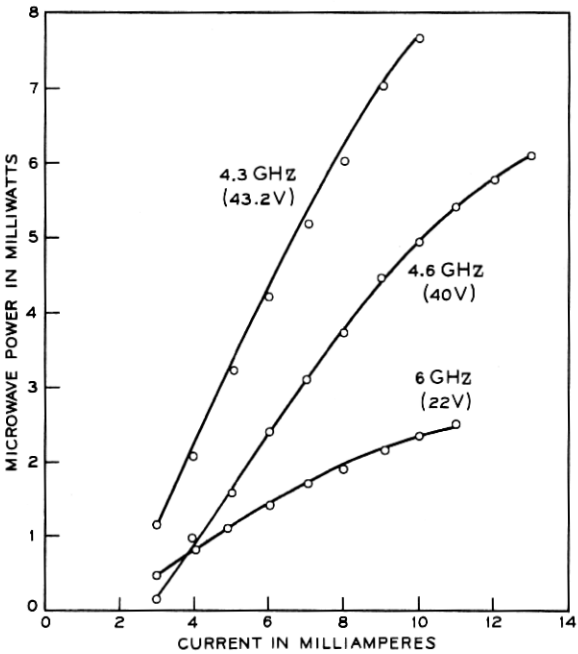

Fig. 3—CW microwave output vs input current for three Si MSM devices. Also indicated are the operating frequency and the average bias voltage while oscillating.

current. This noise measure is considerably lower than that of a silicon Impatt diode and is comparable to that of a GaAs transfer-electron oscillator.

The 6-GHz diode was used to build a stable negative conductance linear amplifier. A gain-bandwidth product of 200 MHz was obtained with 19 dB gain at 5 mA bias. The small signal noise measure was 15 ± 1 dB.

The mechanisms responsible for the microwave oscillations are believed to be (*i*) the rapid increase of carrier injection process caused by the decreasing potential barrier of the forward-biased metal-semiconductor contact and (*ii*) an apparent $3\pi/2$ transit angle of the injected carriers which traverse the semiconductor depletion region. For the 6-GHz diode, the thickness L is smaller. This results in higher frequency (since frequency is inversely proportional to L) and lower critical voltage (which is proportional to L^2). Since the main noise source for thermionic emission processes is the shot noise, one would expect a low noise measure. This is indeed observed experimentally.

If a large barrier height can be obtained for a p-type semiconductor, one can make a complementary MSM structure in the same way as described here. Since the reverse-biased metal-semiconductor contact serves mainly as a blocking contact until the reach-through voltage is obtained, it is conceivable that this contact can be replaced by a p-n junction such as p^+-n-metal structure. By optimizing the material parameters (such as doping profile, barrier heights, and semiconductor thickness) and device geometry and topology,[3] it is believed that higher efficiency and higher power microwave oscillations can be obtained from the MSM and its related structures with the inherent low-noise characteristics.

V. ACKNOWLEDGMENTS

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