Submillimeter Heterodyne Detection with Planar GaAs Schottky-Barrier Diodes

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Abstract—**Planar surface-oriented Pt/GaAs Schottky-barrier diodes have been fabricated and used to detect signals at submillimeter wavelengths. Video detection has been observed up to frequencies as high as 890 GHz. Harmonic mixing between the ninth harmonic of a 74.21-GHz signal and the second harmonic of 333.95-GHz radiation has also been obtained.**

Introduction

THE coupling of submillimeter-wave or far-infrared laser radiation to Schottky diodes is a formidable problem because of the small device dimensions involved. In the past, carefully formed whiskers have been used to provide contact and to serve as a high-frequency antenna. GaAs Schottky diodes using such whisker structures have been shown to be excellent detectors and mixers for submillimeter radiation [1], [2]. However, further development along these lines requires the physical contacting of even smaller devices having submicron dimensions [3]; this procedure has intrinsic limitations. The objective of the present work is to overcome this difficulty by fabricating small, planar, surface-oriented Schottky diodes, in which both terminals of the rectifying junction lie on the same surface of the GaAs wafer. This single-sided geometry lends itself naturally to an integrated circuit approach with the connection of matched stripline antennas and IF filter networks. In addition, the contacting of small devices becomes more feasible. Although devices with this topography have been fabricated previously [4]–[6], they have heretofore been restricted to frequencies below 100 GHz primarily because their relatively large device areas have led to higher capacitance and lower cutoff frequencies. Diodes with diameters as small as 2 μm have been fabricated in our effort, permitting operation at submillimeter wavelengths for the first time.

Device Construction

The geometry of the device is shown in Fig. 1, together with a scanning electron micrograph of the completed device. To fabricate this structure, two layers of GaAs are epitaxially grown on semi-insulating substrates in a hydrogen transport $AsCl_3$ vapor phase system. The first layer (n^+) is 3 μm thick and has an n-type concentration of 1×10^{18} cm^{-3}. The top layer (n) is 0.5 μm thick and has a concentration of 1×10^{17} cm^{-3}. Sulfur (H_2S) is used to dope both layers. Selective Se^+ ion implantation is then used to decrease the specific resistance of the Au–Ge alloyed ohmic contact. After the formation of the ohmic contact, the diode and ohmic contact areas are shielded by gold, and the wafer is proton bombarded, converting the n- and n^+-layers to high resistivity material in the bombarded regions. The sputter deposited Pt/GaAs Schottky barrier is approximately 2 μm in diameter. Each device is contacted by means of a stripline overlay pattern. A photograph showing an array of these devices on a completed wafer is shown in Fig. 2.

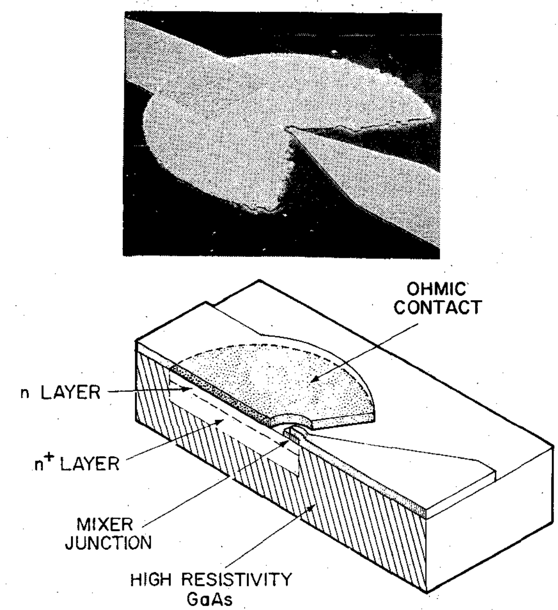

Fig. 1. Bottom: Planar diode as fabricated by growth of n-n^+ epitaxial layers on a high-resistivity GaAs substrate. Top: Scanning electron micrograph showing 2-μm diode (small dot in center), ohmic contact establishing connection to n^+-layer of diode, and two metal strip contacts.

The forward current–voltage (I–V) relationship of a typical device is shown in Fig. 3. This characteristic is quite similar to those of whisker contact Pt/GaAs diodes, with the knee of the nonlinear region occurring at approximately 0.7 V. The n-factors of these devices (describing the deviation from ideal Schottky-barrier characteristics) range from 1.2 to 1.4.

Video Detection

In our preliminary experiments a segment of a device wafer containing a number of diodes was placed on a

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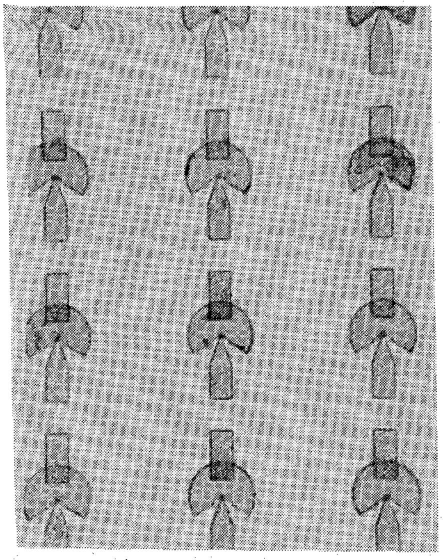

Fig. 2. Array of planar diodes on a GaAs wafer.

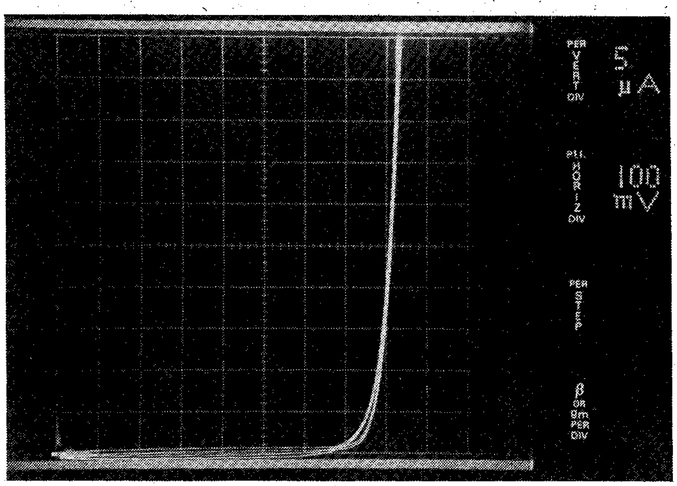

Fig. 3. Forward I–V characteristic of a typical planar diode.

probing apparatus under a microscope so that selected diodes could be contacted while being viewed optically. Various focusing arrangements were used to direct klystron or laser radiation onto the desired spot. In this manner a responsivity of 40 V/W was obtained at 4 mm and about 1 V/W at 337 μm. From these rudimentary results it is not possible to distinguish between intrinsic frequency rolloff of the diodes and variations in coupling inefficiencies at different wavelengths.

Heterodyne Detection

In order to determine the fast response capability of the diodes (that is, demonstrate the nonlinear interaction of high-frequency currents in the device), a number of mixing experiments were carried out. A single device was used which was thermocompression bonded to a stripline on an alumina substrate. First, a carcinotron with an output frequency at 333.95 GHz was mixed with the fifth harmonic of a V-band klystron operating at 66.79 GHz to produce a 90-MHz IF. The S/N obtained was greater than 30 dB. Next, beats were observed, again at a 90-MHz IF, between the ninth harmonic of a 74.21-GHz klystron signal and the second harmonic of the carcinotron operating at 333.95 GHz. Mixing thus occurred at an effective frequency of 668 GHz.

Discussion

Because of their topography, these diodes can be fabricated in large numbers on a single wafer which can be readily integrated with various forms of strip transmission line circuitry. In addition to stripline antennas, numerous other circuit elements can also be integrated with these devices either in a hybrid or monolithic fashion. Some of these concepts have already been successfully demonstrated in the case of thin-film metal–oxide–metal structures [7]. Projected applications of this device involve its use in integrated circuit arrays which are required for large-area coherent detectors and submillimeter imaging devices. Development of simple antennas and arrays is in progress.

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