Schottky-Barrier Diodes for Submillimeter Heterodyne Detection

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***Abstract*—The fabrication and packaging techniques which were used to produce high-reliability mixer diodes for millimeter-wave satellite communications systems have been extended to produce Schottky-barrier mixer diodes for use in the submillimeter-wave region from 1 to 0.1 mm. The influence of material and circuit parameters on the performance of Schottky-barrier diodes as heterodyne detectors in the submillimeter-wave region has been considered. The semiconductor material parameters have been optimized and new packaging concepts have been investigated. A new diode package has been developed which incorporates both an integral stripline filter on 0.05-mm-thick quartz and a section of overmoded waveguide. The new package has the advantage of being replaceable in the mixer circuits, and yet it can provide a low-loss interface between the diode package and the mixer circuit. A new surface-oriented device has been developed in which the contact to the Schottky barrier is formed by photolithographic techniques onto the same surface as the ohmic contact. The surface-oriented devices exhibited heterodyne detection into the submillimeter region.**

Introduction

THE need for reliable low-noise heterodyne detectors in the submillimeter-wave region has become apparent in many areas (e.g., Tokamak plasma diagnostics and submillimeter-wave radio astronomy). The application of low-capacitance GaAs Schottky-barrier diodes as submillimeter heterodyne detectors has been reported previously [1], [2]. These diodes were a low-capacitance version of a high-reliability millimeter-wave mixer diode developed for use in a 38-GHz satellite-to-satellite communication link. The packaging concepts employed for these mixer diodes allowed their use in a relatively simple quasi-optical heterodyne mixer [1] and also in a crossed-waveguide detector [2] even though the circuit environment surrounding the semiconductor device was unsophisticated and somewhat undefined. This paper describes the fabrication and packaging of Schottky-barrier mixer diodes specifically designed for use in the region ranging from 1 to 0.1 mm (300–3000 GHz). The millimeter-wave diode package has been modified to provide an appropriate submillimeter-wave circuit environment while maintaining the basic packaging concepts that resulted in a rugged high-reliability device.

Mixer Theory

The particular constraints which are placed upon mixer design in the submillimeter region and how these constraints affect the design of the semiconductor diode and the diode package are discussed in this section. At submillimeter-wave frequencies the semiconductor device parasitics and the diode package electrical characteristics are important circuit elements, and they must be integrated into the mixer circuit design if optimum performance is to be achieved. Thus it should be obvious that the semiconductor device and the diode package must be designed within the constraints set by the mixer circuit environment. The important question to be answered is: How does one design a mixer diode and an associated mixer circuit environment which will convert power at the signal frequency (RF) to power at a lower intermediate frequency (IF) with minimum loss in the conversion process?

Extensive investigations into the theory of resistive mixers have been published [3]–[5]. In addition to the input resistance R_b of the nonlinear Schottky-barrier junction at the signal frequency, the diode also has a depletion layer capacitance C_j and a series resistance R_s. These so-called diode parasitics C_j and R_s degrade the diode performance as a mixer by introducing additional loss at both RF and IF. Saleh [5] has shown that at submillimeter wavelengths the only mixer circuit that is realizable is the so-called Y mixer in which all the out-of-band frequencies (all frequencies except the local oscillator, the signal, the image and the IF) are short circuited by C_j. Also, to obtain minimum conversion loss in a Y mixer requires the diode to be driven by the local oscillator so that the conducting waveform approaches an impulse train. Under these conditions R_b becomes large, and thus C_j must be small if it is not to short out R_b at the signal frequency. Kerr [6] has shown that for a diode with a given cutoff frequency, $\omega_c = (R_sC_j)^{-1}$, the loss due to RF and IF dissipation in the series resistance R_s is a minimum when the junction resistance R_b is approximately equal to the reactance of the junction capacitance C_j. The signal input should be matched to the junction input resistance R_b, and the IF output should be matched to the junction output resistance. Matching becomes difficult and mismatch loss can become significant if the mixer circuit impedance levels differ widely from the diode junction impedance levels. A consideration of these constraints indicates that a zero-bias junction depletion layer capacitance of about 1 fF (10^{-15} F) should allow reasonable impedance levels to be obtained at 600 GHz.

At millimeter-wave frequencies the diode is usually embedded in fundamental waveguide for which the equivalent circuit and the mixer theory is well known. At submillimeter wavelengths it is very difficult to fabricate

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fundamental waveguide circuits and the waveguide becomes very lossy. Thus at submillimeter wavelengths it seems desirable to build the mixer embedding environment in overmoded waveguide or in a quasi-optical free-space environment. Since in either case the distribution of energy in the various possible modes is not readily known, it is difficult to calculate the coupling to the diode junction and thus to calculate the mixer performance. Scale modeling of the overmoded mixer circuit at lower frequencies, where it is possible to measure impedances and the distribution of energy in the various modes, is probably a useful technique that will enable the overmoded waveguide environment to be evaluated and optimized.

Material and Device Parameter Selection

The basis for the choice of materials and processing techniques for the fabrication of high-quality millimeter-wave diodes has been described in a previous paper [7]. These same considerations apply when selecting material parameters for use in the submillimeter-wave region.

The depletion layer capacitance of a circular Schottky barrier of diameter D on uniformly doped material of carrier concentration n is

$$C_j = \frac{\pi D^2}{4}\left[\frac{\varepsilon q n}{2(\phi - V)}\right]^{1/2} \tag{1}$$

where ε is the permittivity of the semiconductor material, q is the electronic charge, ϕ the contact potential, and V the dc applied voltage.

The RF series resistance R_s has been shown previously [7] to be given by

$$R_s = \frac{4\rho t}{\pi D^2} + \frac{\rho_s}{2\pi\delta}\ln\left(\frac{2b}{D}\right) + \frac{\rho_s}{\pi D}\tan^{-1}\left(\frac{2b}{D}\right) + R_e + R_c \tag{2}$$

where ρ and t are, respectively, the resistivity and thickness of the undepleted epitaxial layer, ρ_s is the resistivity of the substrate material, δ is the skin depth in the substrate material, b is the radius to the outside of an assumed cylindrical chip, R_e is edge resistance, and R_c is the ohmic contact resistance. Since the resistivity is inversely related to the mobility, the advantage of using GaAs because of its high electron mobility is evident. The requirements to minimize both C_j and R_s are in conflict, however, since a reduction in device diameter in order to reduce C_j results in an increase in R_s.

The choice of material parameters for fabrication of submillimeter-wave mixer diodes can now be made. The epitaxial layer should have high mobility and a high carrier concentration. An upper limit to the epitaxial layer carrier concentration is set by the requirement that the device should not be driven into reverse breakdown by the local oscillator drive, since operation in the avalanche region generates considerable noise. The contribution of the epitaxial layer to R_s can be minimized by having the epitaxial layer thickness equal to the depletion layer width at zero bias. To this end, epitaxial layers with thickness of 0.1 μm or less are now used. The contribution from the RF spreading resistance [second and third terms in (2)] can be reduced by using smaller device chips or by fabricating an annular ohmic contact close to the Schottky barrier. If the latter approach is taken, as in the surface-oriented diodes which are described in a subsequent section, the ohmic contact resistance R_c increases as the annular ohmic contact is brought in close to the Schottky barrier, but the total series resistance R_s decreases. At millimeter-wave frequencies the terms R_e and R_c in (2) are small and can usually be neglected. In the submillimeter R_e and R_c will be larger due to the reduced skin depth, and techniques to reduce the contribution from these terms could be worthwhile. Surface roughness or edge cracks could clearly have an effect on the magnitude of R_e, and thus particular attention should be paid to the exposed edges of the chip. At submillimeter wavelengths it may be advisable to polish the exposed chip and to electroplate gold over the exposed semiconductor material. The RF current path from the chip edge to the ohmic contact and the associated contact resistance R_c are difficult to calculate since the contact also has a very large susceptance which will shunt the contact resistance and lead to a much lower effective series resistance. In fact at submillimeter wavelengths the conventional alloyed ohmic contact with its associated alloy-damaged material and coarse interfacial-barrier region may not be the best contact to the heavily doped substrate material. A large area plated or evaporated Schottky-barrier metallization onto the highly polished substrate surface may produce a lower loss contact [7], [8].

Consideration of the above factors indicates that an epitaxial layer of GaAs of thickness 0.1–0.2 μm with a carrier concentration in the range 1×10^{17}–4×10^{17} cm^{-3} should be suitable for the fabrication of submillimeter-wave mixer diodes. A 1-μm-diam diode on a 0.1-μm-thick epitaxial layer of carrier concentration 2×10^{17} cm^{-3} could theoretically have a zero-bias junction capacitance of 1 fF, an RF series resistance of 15 Ω, and, therefore, a potential cutoff frequency of 10 000 GHz.

Diode Fabrication and Packaging

The packaged diode used in the early submillimeter-wave heterodyne detection experiments is shown in Fig. 1 and in detail in Fig. 2. The package consists of two gold-plated copper studs, each 0.64 mm in diameter by 6.1 mm long, soldered into a copper–ceramic–copper annular sleeve. The semiconductor chip is soldered to one copper stud, and a 12.5-μm-diam gold-plated tungsten whisker is soldered to the other stud. The tungsten whisker provides electrical contact to one of the many Schottky-barrier diodes on the semiconductor chip.

The whisker contact probe must maintain reliable contact to the device metallization over the operating temperature range of the device and under specified conditions of mechanical shock (e.g., satellite launch), but it must not damage the device metallization or the semiconductor material or cause long-term degradation in device performance as a result of mechanical stress on the gallium

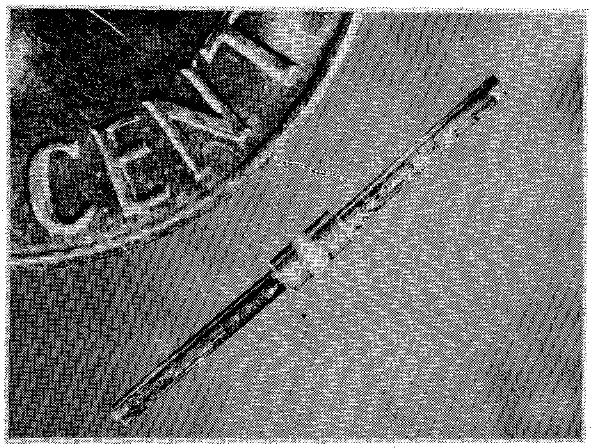

Fig. 1. Packaged millimeter-wave Schottky-barrier mixer diode developed for the Lincoln Laboratory satellite-to-satellite 38-GHz communication link and used in the early submillimeter-wave heterodyne experiments.

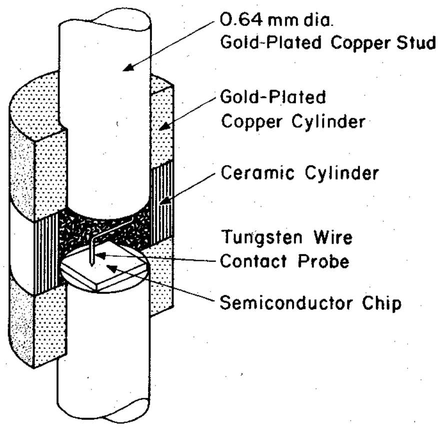

Fig. 2. Cross section of a millimeter-wave diode package.

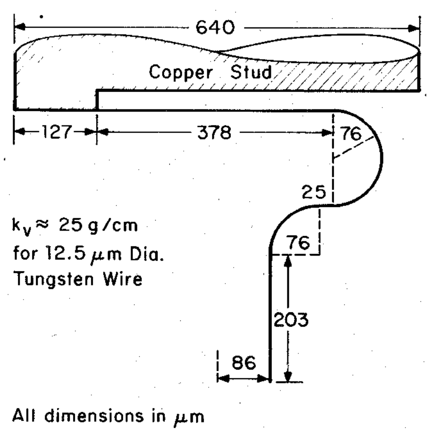

Fig. 3. Shape and dimensions of the tungsten whisker designed to give no lateral deflection when the whisker is compressed vertically.

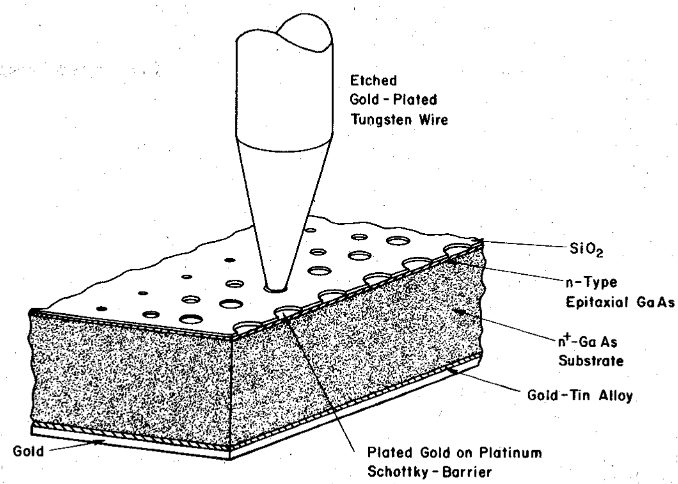

Fig. 4. Structure of the point-contacted Schottky-barrier diode. The Schottky barriers are arranged in six rows, each of different diameter, with diameters in the range 0.5–3 μm.

arsenide. The whisker shape and the parameters shown in Fig. 3 are the result of an extensive design analysis in which several materials (tungsten, molybdenum, gold, and various gold alloys) were evaluated in several possible configurations. The whisker is designed to have no lateral deflection when it is compressed vertically and to exert a stress of less than 7×10^6 kg-m^{-2} (10 000 psi) on the gallium arsenide immediately below the Schottky-barrier metallization. The 12.5-μm-diam tungsten whisker shown in Fig. 3, blunted to a 3-μm tip diameter, exerts a stress of about 3.5×10^6 kg-m^{-2} on the device metallization when compressed 10 μm. The tungsten whisker is bent to shape using a precision bending jig and is then electrochemically etched to length. The resulting conical tip has a diameter considerably less than 1 μm, which is ultrasonically blunted to produce a flat tip of diameter approximately three-quarters that of the Schottky-barrier metallization to be contacted. The etched and blunted tungsten tip is sputter etched to remove tungsten oxides and residual contamination and is then coated with a sputter-deposited layer of gold approximately 0.1 μm thick.

The structure of the point-contacted Schottky-barrier diode is shown in Fig. 4 and is similar to that described by Young and Irvin [9]. The n on n^+ gallium arsenide chip is 0.25 mm square by 75 μm thick. The epitaxial layer has a carrier concentration in the range $1 \times 10^{17} - 4 \times 10^{17}$ cm^{-3} and a thickness of typically 0.5 μm for the millimeter-wave devices and 0.1 μm for the latest submillimeter-wave devices. A protective pyrolytic layer of silicon dioxide approximately 4500 Å thick covers the surface of the epitaxial layer.

The processing of the gallium arsenide wafer begins with a solvent cleaning, and then a protective layer of silicon dioxide is deposited over the epitaxial layer. The substrate side of the wafer is then mechanically lapped to a thickness of 125 μm and chemically polished to a final thickness of 75 μm to remove the work-damaged material resulting from the lapping operation. The wafer is cleaved into approximately 6-mm square pieces which are then processed individually. The ohmic contact to the n^+ substrate is made by electroplating 1000 Å of a 20-percent tin–80-percent gold alloy onto the substrate followed by alloying at 450 °C in a reactive H_2–HCl atmosphere. Approximately 3 μm of gold is then electroplated onto the alloyed surface.

The Schottky barriers are fabricated on the epitaxial layer by first opening holes in the silicon dioxide using 10:1

reduction projection photolithography. A multiple device array with diameters ranging from 1 to 6 μm as indicated in Fig. 4 was used for the early submillimeter-wave heterodyne detection experiments. Superimposed on this array is an array of 12.5-μm-diam diodes on 127-μm-diam centers which are used for material evaluation. The latest submillimeter-wave devices have a similar six-row device array but with diameters in the range 0.5–3 μm. Ultrasonic agitation is used when etching the holes into the silicon dioxide layer in order to improve the yield. The platinum Schottky barriers are formed on the exposed surface of the n-type epitaxial gallium arsenide by electroplating 1500 Å of platinum through the holes in the silicon dioxide, and the platinum is then overplated with 2000 Å of gold. The device metallization is thus recessed into the holes in the silicon dioxide by about 1000 Å. The platinum provides both a metallurgical barrier to prevent diffusion of gold into the epitaxial gallium arsenide layer, and a mechanical barrier to prevent penetration of the Schottky-barrier metallization by the tungsten whisker. Processing is completed by wire sawing the wafers into 0.25-mm square chips.

An alternative technique for fabricating the Schottky-barrier contacts is being investigated. Platinum, gold, and titanium are sequentially sputter deposited onto the surface of the epitaxial layer. Projection photolithography and chemical etching are used to define the device pattern into the titanium layer, and the gold and platinum layers are sputter etched in a 10-percent oxygen, 90-percent argon plasma using the titanium as a mask. Proton bombardment is used to convert a layer approximately 0.3 μm deep below the surface of the exposed gallium arsenide to semiinsulating GaAs. In addition to reducing surface leakage and preventing edge breakdown, the proton-guarded devices have considerably reduced edge capacitance. A 1-μm-diam device formed by this technique has significantly lower capacitance than a 1-μm-diam device formed on identical material by electroplating through a silicon dioxide layer.

Measurements of diode zero-bias junction capacitance as a function of diode diameter for Schottky-barrier diodes located on the same chip are shown in Fig. 5 on the curve labeled "before proton guarding." Also shown is the theoretical depletion layer capacitance relationship given by (1) using the material parameters determined by measurements on the large 12.5-μm-diam diodes. The small area devices depart considerably from the depletion layer capacitance relationship given in (1) in that they have much larger capacitance than is predicted from the material parameters. This increased capacitance presents a severe limitation in the use of these small area devices as submillimeter-wave mixers. Correction of the theoretical curve to account for the diode edge capacitance described by Copeland [10] does not account for the increased capacitance observed. Apparently, there is additional edge capacitance associated with the smaller diameter diodes which can be partially eliminated when the material surrounding the Schottky barriers is converted to semiinsulating GaAs by proton bombardment. The zero-bias capacitance of the diodes after proton guarding is shown in

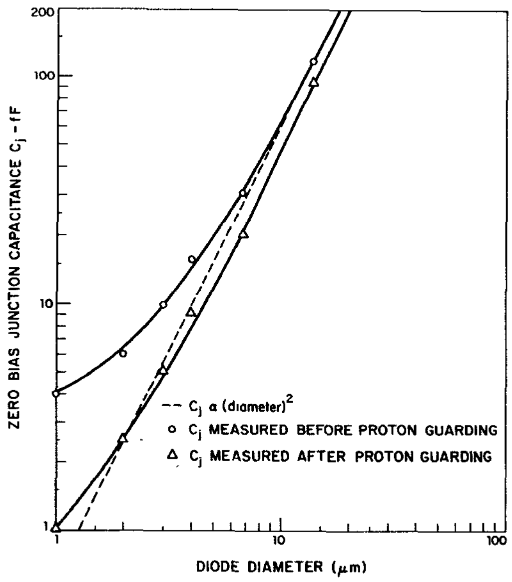

Fig. 5. Diode zero-bias junction capacitance versus diode diameter before and after proton guarding.

Fig. 5. The diodes also have improved reverse dc voltage–current characteristics after proton guarding since surface leakage is eliminated. The dramatic reduction in the diode junction capacitance for proton-guarded small area devices makes this technique particularly attractive in the fabrication of submillimeter-wave devices. The cause of the excessive edge capacitance of the small area Schottky-barrier diodes shown in Fig. 5 is not completely understood.

Assembly of the diode takes place in a jig which maintains the two gold-plated copper studs (shown in Fig. 2) in precise alignment while one of the several possible diodes which can be positioned below the tungsten tip is contacted and evaluated for electrical performance. Selection and contacting of an individual diode is observed under a high-power optical microscope. The tip of the tungsten whisker is located approximately 0.09 mm from the axis of the whisker stud as shown in Fig. 3 so that, as the chip stud is rotated about its axis, only those diodes which lie on a 0.18-mm-diam circle concentric with the axis of the chip stud can be positioned below the tip of the tungsten whisker. Typically, ten diodes from each diameter size can be contacted in one complete rotation of the chip stud. The tip of the gold-coated tungsten whisker is lowered into a selected hole in the silicon dioxide to contact a diode (in contrast to the more usual technique of sliding a pointed whisker across the surface until it comes to rest on a diode). When an appropriate diode is contacted, the tungsten whisker is compressed 10 μm and is maintained in compression while the copper–ceramic annular sleeve is moved into position. The package is fluxless solder sealed in an inert nitrogen environment, resulting in an hermetically sealed and extremely rugged package. During the solder-sealing operation, thermal expansion of the copper studs causes an impulsive force to be exerted by the tip of the tungsten whisker which is sufficient to cause cold bonding of the gold on the tip of the tungsten whisker to the gold

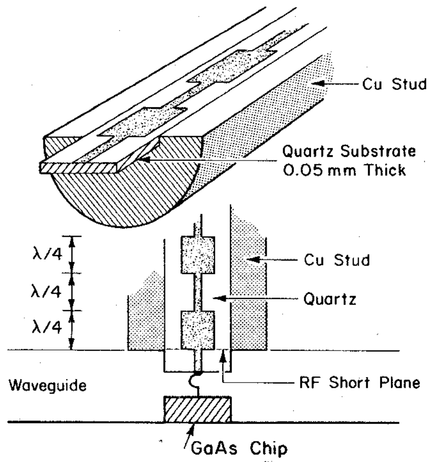

Fig. 6. Detailed view of one-half of a stripline filter inserted into a diode stud and mounted in a section of waveguide.

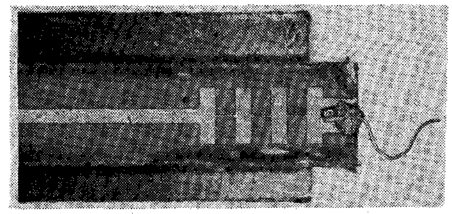

Fig. 7. Seven-section stripline filter in a 0.4-mm-wide channel milled into a half-round copper stud with tungsten whisker attached and etched to length. (Quartz cover and stud cover have been removed.) Separation between filter sections is $\lambda/4$ at the operating wavelength.

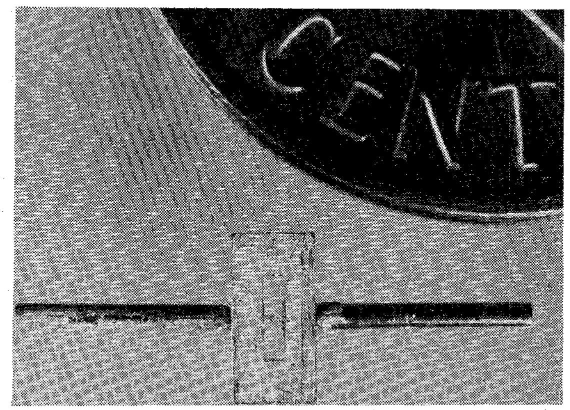

Fig. 8. Submillimeter-wave mixer diode with integral stripline filter and overmoded waveguide package.

metallization of the device. Since the differential thermal expansion of the ceramic annular sleeve with respect to the tungsten whisker–gallium arsenide chip is only $2 \times 10^{-6}/°C$, the package can be cooled to liquid helium temperatures with no loss of contact to the semiconductor device.

Submillimeter Diode Package Mixer Environment

The diode package shown in Fig. 1, which was used in the early submillimeter-wave heterodyne experiments, could not be integrated into an optimally designed submillimeter-wave mixer. The diode studs are too large in diameter to allow the use of coaxial bias filters of the type used at lower frequencies because waveguide mode propagation would be possible in such structures. The copper–ceramic package introduces a major dielectric discontinuity which would make optimum coupling of the submillimeter-wave radiation into the device difficult. Clearly, a different packaging configuration is required for an optimum submillimeter-wave mixer circuit environment in the vicinity of the diode. However, it is desirable to maintain the concept of a replaceable diode package and to utilize as much as possible of the packaging technology and reliability design that has been developed for the millimeter-wave diodes. Accordingly, a quartz stripline filter fabricated on 0.05-mm-thick quartz was inserted into the center of a modified whisker stud, as shown in Fig. 6. The ceramic–copper sleeve was replaced by a short section of overmoded waveguide. Stripline was chosen for the integral filter to reduce the mode coupling problems that have been observed with microstrip [11]. Overmoded, reduced-height N guide was chosen for the waveguide package to minimize the waveguide loss at the submillimeter wavelengths. The waveguide-package dimensions are held to very close tolerances so that the diode package can be accurately located in a submillimeter mixer environment with very low loss at the waveguide interfaces. The diode fabrication and packaging techniques are similar to those described above for the millimeter-wave diodes. Inclusion of a stripline filter into the whisker stud results in a frequency-dependent device, but otherwise all the advantages of a replaceable diode package remain.

A seven-section filter structure with 20- and 100-Ω quarter-wavelength line selections was selected for the integral filter since this gave adequate filter characteristics (>40-dB insertion loss at the signal and local oscillator frequencies), and it could be accommodated in the center of the 0.64-mm-diam whisker stud used in the millimeter-wave mixer diode package. The filters are fabricated on 19 mm square by 0.05-mm thick quartz substrates using conventional photolithographic techniques to pattern an evaporated 250 Å Cr/3 μm Au coating. Filter structures designed to operate at 55, 300, 600, and 890 GHz are produced in the metallization on one surface of the quartz. After fabrication, the filters are separated by sawing the quartz into 0.36 by 6.1-mm strips. A preshaped tungsten whisker is soldered to the bonding pad at the end of the filter section. The quartz strip is soldered into a rectangular channel 0.38 mm wide by 0.08 mm deep which has been milled into one-half of a 0.64-mm-diam copper stud as shown in Fig. 7. A quartz cover section to form the other half of the stripline circuit environment is placed in the channel over the filter strip and a copper cover stud is soldered in place to complete the integral-filter whisker-stud assembly. Etching the tungsten whisker to length and final whisker shaping complete the whisker-stud fabrication procedure. A completed submillimeter-wave diode with an integral bias filter and waveguide package is shown in Fig. 8.

Calculations indicate that, for 0.05-mm-thick quartz substrates, the fringing fields associated with the step changes in stripline width would considerably modify the behavior of filters designed to operate above 600 GHz. Since measurement of filter characteristics at submillimeter

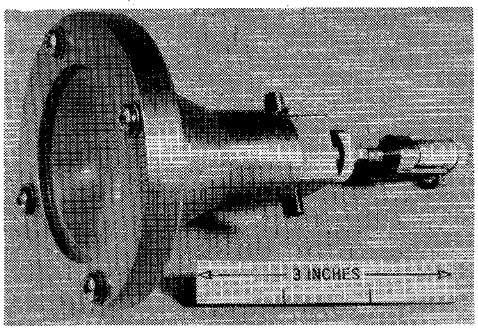

Fig. 9. 600-GHz mixer. The radiation is focused onto the mixer diode which is mounted at the focal point of the horn-lens (TPX) antenna in reduced-height *N* guide. A tunable back short is located in reduced-height guide immediately behind the diode.

wavelengths is extremely difficult, filter dimensions were scaled up by a factor of 100 so that measurements could be made in the 1–9-GHz range. These measurements would correspond to measurements on the submillimeter filters in the range 100–900 GHz. Scaled modeling proved to be a powerful diagnostic tool, and essential to evaluate the potential performance of mixer components in the submillimeter-wave region. The quartz substrate in the model filter became 38 mm wide by 5 mm thick, and a length of 152 mm was adequate to accommodate the seven-section quarter-wavelength filters scaled to operate at 3.0, 6.0, and 8.9 GHz. For the model the chrome–gold metallization was replaced by adhesive backed copper foil, which was readily cut to the scaled filter dimensions. Measurements of the impedance levels, effective lengths, and location and magnitude of discontinuity reflections of the stripline circuits were made by time domain reflectometry using a 35-ps risetime system. The transmission and reflection characteristics of the scaled model filters were measured on an automatic network analyzer over the frequency range 1–12 GHz. These measurements indicated that the 300- and 600-GHz filters should perform as designed, but that edge effects would limit the operation of the 890-GHz filter structure to a frequency only slightly greater than 600 GHz.

A 600-GHz mixer designed to use the integral-filter waveguide-packaged diodes is shown in Fig. 9. A horn-lens (TPX) antenna is used to couple the submillimeter radiation into the diode, and a tuning backshort is located immediately behind the diode in a section of reduced-height waveguide. DC bias for the diode and the IF output are provided through the integral stripline filter which connects to a miniature coaxial connector mounted on the mixer body. Measurements on this structure are now in progress. Advanced quasi-optical mixer mounts which use the new integral-filter waveguide package diodes are also being studied.

Surface-Oriented Device Technology

As diode diameters are reduced, the contacting problem becomes more difficult and the sensitivity of the device to electrical transients is much greater. Considerable advantages could be gained by fabricating the diode contact and the mixer circuit directly onto the diode chip. To this end, a surface-oriented mixer diode has been designed [12]. The structure of the surface-oriented mixer diode and an SEM photograph of a fabricated diode are shown in Fig. 10. Proton bombardment is used to isolate the conductive device regions in an n on n^+ epitaxial layer grown upon a semiinsulating substrate. The three-quarter annular pie-shaped ohmic contact surrounding the 2-μm-diam Schottky-barrier junction is formed by selective ion implantation which converts the n-layer to n^+ in the region under the ohmic contact. Alloying of the contact metallization completes the fabrication of the ohmic contact. The Schottky-barrier rectifying junction is platinum on gallium arsenide. Both the gold terminal contacting the alloyed and implanted ohmic contact and that contacting the 2-μm-diam platinum Schottky-barrier junction lie on the same surface of the GaAs wafer, and extend out from the conductive device pocket over semiinsulating gallium arsenide. Because of its single-sided geometry, this device can readily be integrated into microstrip or stripline circuitry.

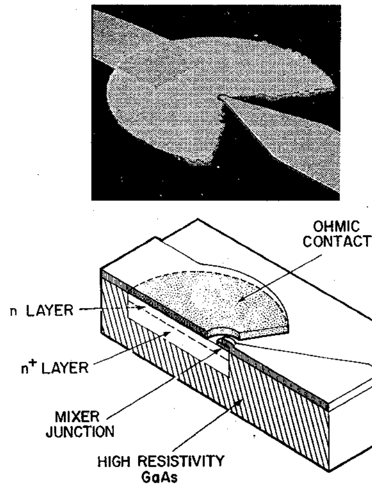

Fig. 10. Bottom: Structure of the surface-oriented diode showing the n on n^+ epitaxial regions converted to high-resistivity GaAs by proton bombardment. The n-layer immediately under the ohmic contact is converted to n^+ by ion implantation followed by alloying of the contact metallization. The Schottky-barrier mixer junction is 2 μm in diameter. Top: SEM photograph showing the three-quarter annular ohmic contact, the diode junction (small dot in the center), and the two metal surface contacts.

Surface-oriented GaAs mixer diodes mounted in a simple microstrip circuit have been used to detect signals at frequencies as high as 890 GHz. They have also produced an IF response arising from the mixing of the ninth harmonic of a 74.2-GHz signal with the second harmonic of a 333.95-GHz signal. Modified *H* guide [13] appears to have some attractive features which could result in low-loss waveguide mixer structures when combined with the surface-oriented mixer diodes. Antenna structures [14] can be fabricated on the semiinsulating GaAs in close proximity to the diode junction which should allow better coupling of the submillimeter radiation into the nonlinear mixer element. Such structures used in a quasi-optical mixer mount could be the basis for a high-efficiency submillimeter-wave mixer. As technology develops, the aim is for a completely integrated optical receiver in which the diode, an optical waveguide circuit, and an appropriate antenna coupler are fabricated on a single piece of gallium arsenide.

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Submillimeter-Wave Detection with Submicron-Size Schottky-Barrier Diodes

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***Abstract*—Schottky-barrier diode detection has been extended to 7.2 THz (42 μm) using 0.5-μm-diam diodes. The diodes were fabricated on bulk-doped n-type GaAs using electron lithographic techniques; diameters as small as 1000 Å have been achieved. A new approach in Schottky-barrier design, the contact array diode, is proposed. The diode is fabricated from readily available bulk doped material, and a performance is indicated that is competitive to the conventional epitaxial Schottky-barrier mixer well into the submillimeter wavelength region. A scanning electron microscope (SEM) photograph of diode array structures is shown.**

I. INTRODUCTION

THE work described in this paper consists of two parts. The first part summarizes Schottky-barrier diode detection measurements at wavelengths of 42 μm (7.2 THz)–1222 μm (245 GHz) using submicron dimensional Schottky-barrier diodes mounted in an open nontunable mount. Video detection at 42 μm represents the shortest wavelength for Schottky-barrier detection to be reported in the literature. The diodes were 0.5 μm in diameter and were fabricated from nonepitaxial heavily doped n-type GaAs. These ultrasmall, and consequently ultralow capacitance, junctions were prepared using electron beam lithography [1] and have yielded the smallest series-resistance junction-capacitance product to be reported in the literature for a Schottky-barrier diode. The advantages of this doping and structure as well as preliminary video detection and heterodyne mixing measurements at 70–1222 μm have been recently described [2].

The second part of the paper explores the application of this submicron dimensional technology to the fabrication of a Schottky diode mixer employing a tunable mount. A straightforward application of this technology to the fabrication of efficient Schottky-barrier mixers is hampered by conversion loss limitations associated with the imped-

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