SUBMILLIMETER WAVELENGTH SURFACE-ORIENTED DIODE MIXERS*

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ABSTRACT

Schottky barrier diodes in which proton bombardment has been used to define small surface-oriented devices have been used as submillimeter wavelength mixers. High-order harmonic mixing and direct heterodyne mixing with lasers up to 761 GHz have been achieved.

Introduction

Video detection at frequencies as high as 890 GHz (337 μm) and harmonic mixing between 74.21 GHz and 333.95 GHz signals using small surface-oriented Schottky barriers have been previously reported.[1] Further development of these devices has resulted in improved performance at shorter wavelengths. Improved coupling schemes have resulted in high-order harmonic mixing and direct heterodyne mixing with laser signals.

Device Construction

The details of the device construction are shown in Figure 1. Proton bombardment is used to fabricate (in a planar geometry) small devices appropriate to the submillimeter wavelength regime. Both terminals of the diode lie on the same surface and are contacted by fabricated metal overlays. The devices are made with material in which two epitaxial layers of GaAs are grown upon a semi-insulating substrate in a $AsCl_3$-Ga-H_2 vapor-phase system. The first of these layers (n^+) is approximately 3 μm thick and has an n-type concentration of $1 \times 10^{18} cm^{-3}$. The top layer (n) is 0.2 μm thick and has a concentration of $1\text{-}2 \times 10^{17} cm^{-3}$. Sulphur ($H_2S$) is used to dope both layers. Selective Se^+ ion implantation, using phosphosilicate (PSG) as a bombardment mask is used to decrease the resistance of the ohmic contact. The Se^+ is implanted into the ohmic contact areas through a 500 Å pyrolitic silicon nitride layer, which also serves as the encapsulant for the post-implantation anneal. After this anneal (850°C, for 15 min) the silicon nitride is removed and the eutectic Au-Ge is sputter deposited. The Au-Ge is alloyed in a reducing atmosphere containing gaseous HCl as a flux, lifted off by dissolving the PSG and then plated with Au. After the formation of the ohmic contact, the Schottky barrier and ohmic contact regions are shielded with a plated Au layer and the wafer is bombarded with protons energetic enough to convert both the n- and n^+ layers to high resistivity material in the regions bombarded. The bombardment mask is then removed and the Schottky barrier is formed. Both platinum and titanium have been evaluated as Schottky barrier metals. E-beam deposited titanium appears superior because its n-factor, 1.05, is lower than that of the platinum, 1.2. Devices as small as 2 μm in diameter have thus far been fabricated using projection printing; 1 μm diameter devices should be producible with the present techniques and equipment. After the Schottky barrier contact area is formed, the wafer is proton bombarded again with low-energy protons capable of converting the n-layer only. The contact areas are shielded from the protons by their metallizations. This procedure defines the Schottky barrier contact area more precisely and reduces excess capacitance. A metal overlay contact with the desired circuit properties is then fabricated, completing the device.

Electrical Characteristics

The electrical characterization of these devices is complicated by the topology of the device. The metal overlays give rise to comparatively large fringing capacitance which appears in parallel with the Schottky barrier junction in low frequency (1 MHz) measurements. However, part of this capacitance arises from the distributed capacitance of the transmission line involved and will not be parasitic to the device in a properly designed circuit. A surface-oriented diode which has been fabricated on a single chip and contacted with a microstrip-like overlay is shown in Figure 2. Low frequency measurements made on these devices lead to the equivalent circuit which is also shown in Figure 2. The zero-bias capacitance together with the measured series resistance lead to a zero-bias cut-off frequency of 1136 GHz.

Submillimeter Measurements

Figure 3 shows devices to which planar radiating structures have been attached. These metal patterns were designed as half-wavelength dipoles[2] at wavelengths ranging from 0.5 to 1 mm. However, the radiation patterns of these devices show complex lobe structures in this wavelength range, apparently because of interference from other radiating elements. A typical radiation pattern obtained at 348 GHz, is shown in Figure 4. Our measurements indicated that modes are excited in the GaAs substrate, with the result that the whole GaAs slab acted as a radiating element. Even though some of the lobes are quite narrow, it is desirable to work with simpler and more controllable structures. Consequently we have begun to make measurements upon scale models of slot and coplanar antennas. These measurements have indicated that energy can be coupled quite efficiently to the nonlinear junction with these radiating structures. Submillimeter devices using these structures will be fabricated. Other antenna configurations are also under consideration.

Although no accurate quantative measurements of the sensitivity of these devices have been made, they have been successfully used as detectors and mixers well into the submillimeter wavelength regime. It has become apparent in heterodyning with pulsed laser sources that in electrically noisy environments planar diodes show better survival and noise suppression characteristics than conventional whisker[3]-contacted diodes and in addition display remarkable physical ruggedness. High order harmonic mixing has been obtained by coupling a 9.2879 GHz signal introduced into the IF and a 862.196 GHz (393.6 μm) laser line of formic acid to a planar device. The IF response corresponded to the 82nd harmonic of the X-band signal and had a signal-to-noise ratio of better than 35 dB. This same system of harmonic mixing has been used to phase-lock our 1 mm carcinatron and is used to routinely for that purpose.

In a related experiment, the pulsed output of a D_2O laser operating at 779.2 GHz (385 μm) was mixed with the 762.2 GHz (393.6 μm) laser line of formic acid, producing an IF response at 17 GHz and demonstrating the wide bandwith capabilities of the mixer. In addition we have exploited this technique to make detailed heterodyne measurements of the pulsed D_2O laser's bandwidth and spectral purity.

The responsivity of the diode at submillimeter wavelengths, approximately calculated from estimates of the absorbed laser power, does not differ appreciably from that obtained at longer wavelengths. With improved coupling to the device, black body radiometric measurements will become possible so that an accurate determination of the noise temperature of the diode can be made. This will allow a quantative assessment of the capabilities of the planar diode and will also allow a more meaningful comparison of these devices with conventional whisker-contacted Schottky barrier diodes.

References

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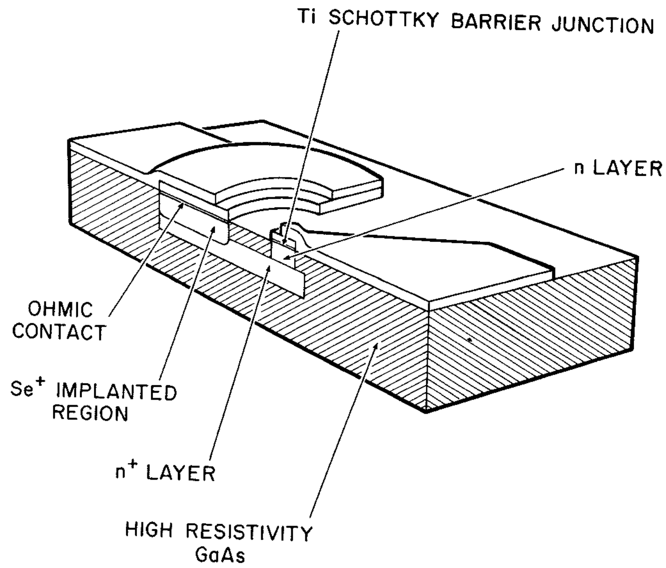

Figure 1. Construction of surface-oriented diode. The device is fabricated from n- n^+ epitaxial layers on a high resistivity substrate. A metal overlay contacts the nonlinear junction which is approximately 2 μm in diameter.

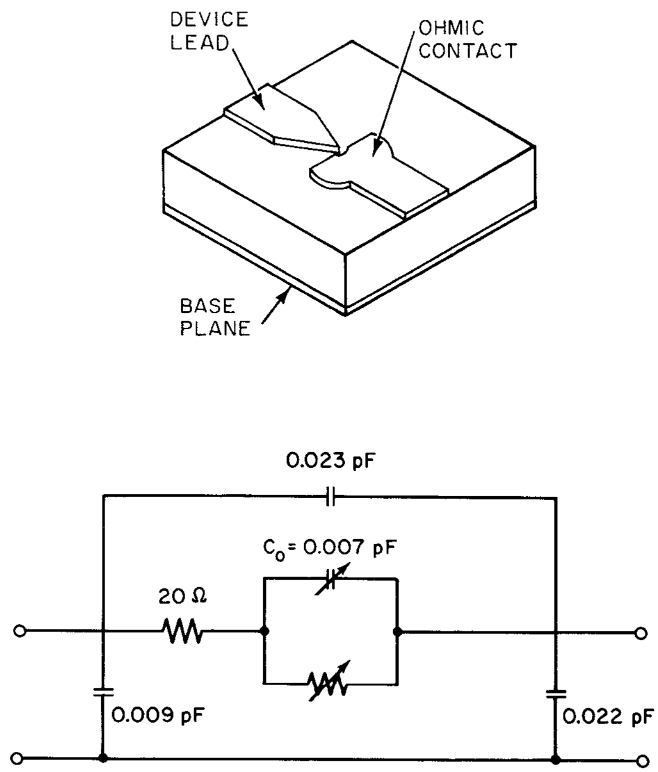

Figure 2. Top: Topography of the device evaluated by low frequency measurements. Bottom: Low frequency equivalent circuit of this device.

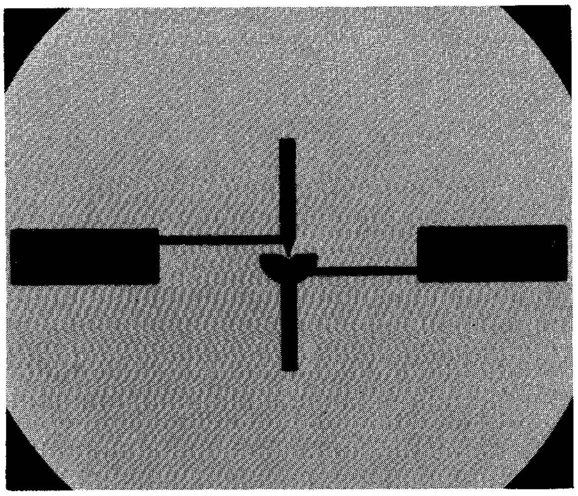

Figure 3. Surface-oriented devices to which half-wave-length dipoles have been attached. The vertical metal structure is the dipole; remaining metallization was designed to extract the IF signal.

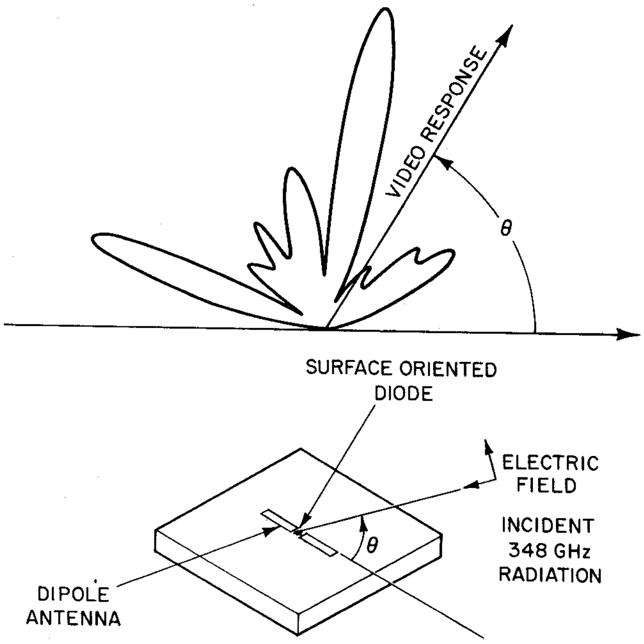

Figure 4. Antenna response of surface-oriented diode with attached dipole antenna pattern. The complex radiation pattern appears due to the excitation of modes in the GaAs chip.