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DETECTION AND MIXING OF VISIBLE AND INFRARED RADIATION BY InP AND InSb SCHOTTKY BARRIER DIODES

A. Bertolini[1], N. Beverini[1], G. Carelli[1], S. Chepurov[2], E. Maccioni[1], A. Moretti[1] and F. Strumia[1]
[1] - Dipartimento di Fisica dell'Università di Pisa, GNSM and INFM
[2] - Institute of Laser Physics, Siberian Division of Russian Academy of Sciences

Giorgio Carelli, Dipartimento di Fisica dell'Università di Pisa, via Buonarroti 2, I-56127 Pisa, Italy
Tel. +39—050–844 285, Fax. +39—050–844 333,e-mail carelli@difi.unipi.it

ABSTRACT

We present the results of the experimental investigation of the detection and mixing properties of Schottky barrier diodes in the visible and near infrared regions. We used diodes with different semiconductor substrates, GaAs, InP and InSb, and different contact geometries. We used the diodes in the regions 458 – 633 nm and 1.3–1.5 μm. The video signals from the different devices were measured together with the beat notes from different modes of the visible lasers and high order harmonics of a microwave radiation. In the visible the GaAs-diode proved to be a very effective detector but has a very low frequency conversion efficiency and it generated no beat signal below 510 nm. On the contrary, InP and InSb-SBD operate very effectively as mixers, even with relatively low detection efficiencies, up to the blue. In the region 1.3 –1.5 μm the GaAs diode does not work while InP and InSb continue to be effective.

1. INTRODUCTION

In the past few years Schottky barrier diodes (SBD) have raised great interest due to their advantages over other devices in heterodyne detection in a very large wavelengths range. These diodes operate at room temperature and present a very high operation speed and a much higher stability than conventional Metal-Insulator-Metal (MIM) diodes. For these reasons they have been used extensively for nonlinear frequency mixing in the MM, SMM (FIR), IR ranges, [1-6]. The extension of these operations to the visible region has a large metrological interest, but only a few works dealing with MIM and Schottky diodes in the visible have been published up to now [7-9].
A mixing signal up to 1 THz has been observed with MIM- diodes as a difference of two green laser lines [7] or two dye lasers [9]. The signal-to noise ratio however was quite poor with a large and unpredictable spread of performance between different diodes. Point-contact Schottky diodes have demonstrated more efficiency and more reliability [8]. Recently an attempt was made to utilize the silver plasmon resonance to enhance the mixing signals of a point contact device for visible radiation at 633 nm from an He-Ne laser. [10], but till now there are no significant improvements over earlier devices.

In the present paper we report the results of an experimental investigation on the mixing and detection properties of point-contact diodes at visible frequencies by using as semiconductor substrates new materials (InP and InSb) and comparing their performances to those of conventional GaAs diodes. Our results demonstrate a better behaviour of these devices as detectors and mixers for visible light with respect to conventional MIM diodes and prove a dramatic enhancement in the signal to noise ratio with respect to GaAs Schottky diodes when used as mixers; these results make them very attractive for use in spectroscopy, laser frequency measurements and metrology.

2. Experiment and results

The investigated diodes presented two types of structure: honeycomb and point contact. GaAs and InP diodes were produced in the Semiconductor Institute (Tomsk, Russia), in collaboration with the Institute of Laser Physics (Novosibirsk, Russia) with an honeycomb structure with window diameters of 1.65 μm and 1.5 μm, respectively [1, 5, 6]. InSb and InP diodes were assembled in the Physics Department of the Pisa University with a classic point contact structure with a large semiconductor platelet as the post [11]. The contacts to the semiconductor posts are made by a tungsten whisker, electrochemically etched to the desired tip radius by means of a 2N solution of NaOH.

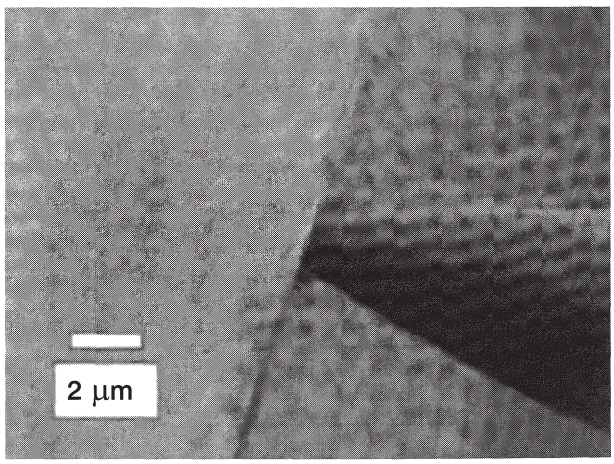

Fig. 1 Photo of the InSb –W junction

We used wires of 30 µm in diameter for the honeycomb diodes while a 127 µm wire was used for the point contact diodes. The curvature radii of the tips were around 50-60 nm, controlled together with the geometry of the contacts by a Scanning Electron Microscope. The InSb crystals have a carrier density of about 10^{14}, InP of 10^{12}, at 77 K. InSb proved to be a soft material and the tip just penetrate the semiconductor surface, in the case of InP, a material harder than InSb, a gold layer was deposed on the surface in order to ensure stable and ripetitive contacts.. A gold coated crystal shows a better video signal in comparison to an uncoated one while the mixing signal does not show signative differences.

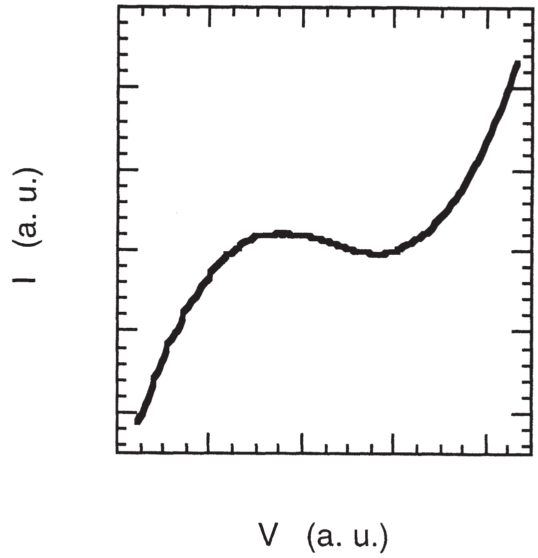

Fig. 2 Non-linear part of the I-V characteristic of an InSb Scottky diode

The I-V characterstic of the different device are completely different and InSb is the only one showing a symmetric one.

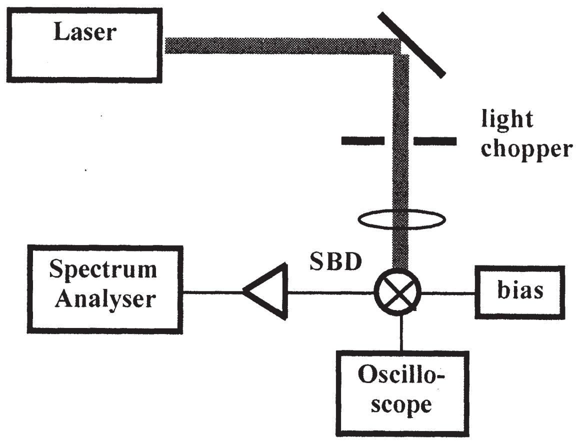

Fig. 3. The experimental setup.

The characteristic of the InP SBD made in Tomsk are classical ones, that of the devise made in Pisa shows an asymmetry between forward and reverse bias, the reverse is closer to a line; the InSb characteristic is close to an ohmic contact, but the non linear part shows a very interesting shape, fig. 2.

The experimental setup for the investigation of the diodes response is schematically shown in Fig. 3. It consisted of a laser radiation source, a microwave source, an SBD and an oscilloscope or a spectrum analyzer as the registering apparatus. The laser radiation was focused onto the SBD by a lens of 10-mm of focal length and the RF radiation was coupled to the diode from an HP 8350B sweep oscillator directly by a microwave horn.

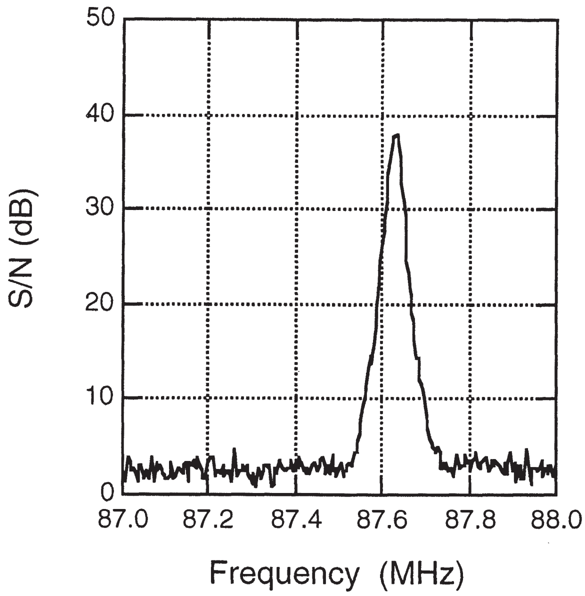

Fig. 4 Beat note betwwen two longitudilal modes of an He-Ne laser, generated by an InSb SBD.

At 633 nm we used as the laser source an He-Ne-laser with an output power of about 7 mW, typically working on two adjacent longitudinal TEM_{00} modes. In the green and the blue we used an Ar-ion laser, with an output power of about 50 mW.. In the infrared diode lasers were used. We measured the rectified videosignals by an oscilloscope. Fig.4 shows the tipical beat detected by the spectum analyzer

In the whole explored range of visible wavelength the GaAs diodes give always the largest video signals, fig.5. We have also tested the frequency mixing properties of the devices by sending the detected signal after amplification in a spectrum analyzer with a bandwidth of 100 kHz and observing the beat notes between different radiation modes of the He-Ne laser and up to the 25th harmonic of the microwave radiation.

In Fig. 6 we show the experimental results for mixing. As mixers, both InP- and InSb diodes proved to be largely more effective than GaAs. The intermode beat signal of the He-Ne-laser at f_b = 875 MHz was observed with a signal-to-noise (S/N) ratio of 70 dB and 68 dB by using respectively InP- and InSb-diode, against only 40 dB with GaAs-SBD. Similarly, the intermode beat signal at f_b = 130 MHz e Ar-laser was observed with a S/N ratio of about 55 dB, 58 dB, and 20 dB, for InP-, InSb-, and GaAs-diodes, respectively. No beat notes were observed by GaAs diodes below 514 nm, while beat notes up to f_b = 5 GHz (that is in the limit of the gain linewidth of the Ar laser) have been observed with InP and InSb diodes

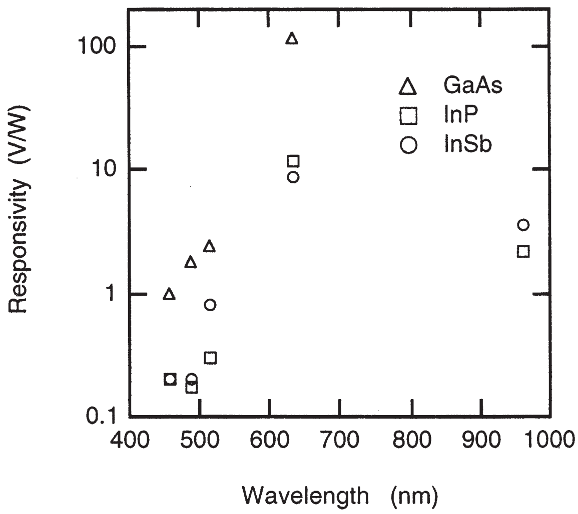

Fig. 5 Video signals obtained by the different SBD

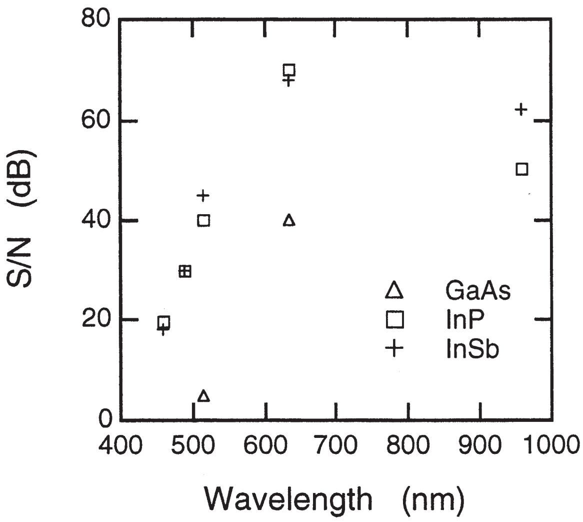

Fig. 5 Mixing signals obtained by the different SBD

In high order mixing experiments, when we applied the microwave power, there was a moderate decrease of the observed beat note signal, but the S/N ratio was still good up to the 27th order of mixing. For example for the InP diode with the He-Ne laser radiation, the application of the MW power led to a decrease of some eight dB of the second order signal; the third order signal presented a S/N ratio of 58 dB and we still had a 18 dB S/N for the twenty-seventh-order signal. It is obviously to be noted that our experiments were carried out in presence of much less power with respect to the previous experiments with GaAs or MIM diodes.

3. CONCLUSION

The results of our experiments showed that the various SBD have different mixing and detection properties. The GaAs-SBD proved to be a very effective detector but has a very low frequency conversion efficiency in the visible. On the contrary, InP- and InSb-SBD operate very effectively as mixers even with relatively low detection efficiencies. This behaviour is quite similar to the results obtained in previous works using infrared radiation [6, 7].

These results can be used in the practical work of construction of different systems of measuring and synthesizing laser frequencies in the visible range and other fields of practical application where there is a need to use nonlinear devices having high sensitivity, high speed of operation, high mechanical stability and ability to work at room temperature

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