# The response rate of room temperature terahertz InGaAs-based bow-tie detector with broken symmetry


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***Abstract* — A bow-tie InGaAs with broken symmetry has been designed for terahertz detection at room temperature. An active part of the detector consists of a two-dimensional electron gas which is heated non-uniformly with incident radiation. Main detector performances are operation in a passive scheme, flat frequency response up to 1 THz, the voltage sensitivity of about 5 V/W, the noise equivalent power of roughly 10 nW/Hz$^{1/2}$, and the response time less then 7 ns.**


## I. Introduction

The progress of terahertz (THz) technology involves new concepts in developing compact broad-band THz sensors operating at room temperature[1]. Particular attention is given to the increase of the response time giving advantage of their versatility in recording circuits used for imaging, medical diagnostic, communication, and security aims.

In this work, we report an experimental study of transient properties of the InGaAs-based bow-tie diode with a broken symmetry. The operation principle is based on a non-uniform carrier heating in a high-mobility electron gas layer[2-3]. Electromagnetic waves detection on mobile carrier heating promises much faster detector response in comparison to bulk detectors of thermal action, for example thermopile, bolometer etc. Here we demonstrate the potential of the THz detector connected in a passive detection scheme and in common with the fast low-noise current preamplifier.

## II. THz Detector

The design of the detector is shown in Fig. 1. The active part is an $In_{0.54}Ga_{0.46}As$ layer grown by molecular beam epitaxy on a semi-insulating substrate of InP (001). The thickness of the InGaAs layer is of about 534 nm. The width of the apex is of 12 µm, and the length of InGaAs leaf and metallized 'right' leaf is of 50 µm and 250 µm, respectively. The concentration of free electrons is of the order of $2\times10^{15}$ cm$^{-3}$ and the low-field mobility is of about 13300 cm$^2$/Vs at room temperature. The Ohmic contacts are made of Ti/Au/Pt compound evaporated and annealed on top of the InGaAs layer. One of the structure's leafs is metallised in order to concentrate an incident radiation into the neck. The mesas of the height of a few micrometers are created by wet etching. After cleaving of the wafer, the sample is wired and attached to a hemispherical silicon lens of 6 mm diameter from the substrate side. All elements are then mounted in the cylindrical metal case with 29 mm diameter and 32 mm length. Image of the THz detector is shown Fig. 2.

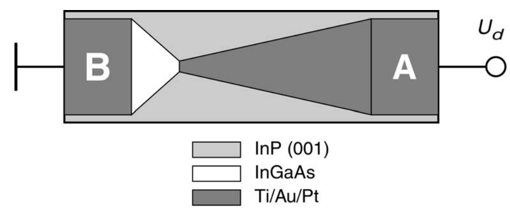


Fig. 1 Top view of the bow-tie InGaAs detector with broken symmetry formed on the InP substrate. The total length of the device is of 500 µm and the width is of 100 µm. The contacts are labelled as A and B to clarify the polarity of applied voltage. The electric field of the incident THz radiation is oriented along the contacts.

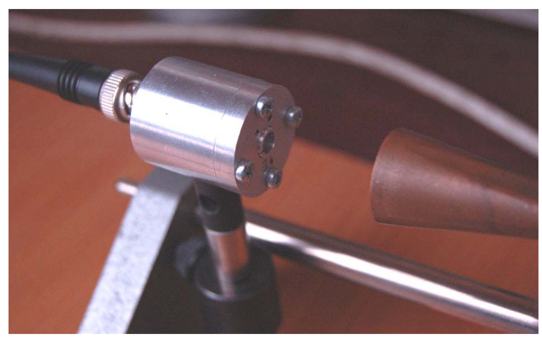

Fig. 2 Photograph of the THz detector fitted to the present work experiments.

The principal of the THz detector operation relays on non-uniform carrier heating in high-mobility electron gas. The metallized leaf acts as a coupler of the incident radiation, while the second leaf is active where electrons are heated non-uniformly. Consequently, the voltage signal with a polarity corresponding to the hot-carrier effect is induced over the leaves without any application of the dc-bias.

The measured $I/V$ characteristic of the asymmetrically shaped diode is shown in the Fig. 3. The reverse bias voltage corresponds to the polarity when contact A is positive and contact B is negative, and the forward bias is vice versa. At low electric field the current magnitude does not depend on the polarity of the voltage applied. But, when the sample is turned to a strong field regime, the temperature of electrons increases and they accumulate differently in the vicinity of the detector neck. This affects on the symmetry of the $I/V$ characteristic and can be applied to detect the THz radiation

An asymmetrically shaped diode is sensitive to the polarization of the incident electromagnetic wave. The strongest signal is obtained when diode is oriented along the


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direction of the electric field. The difference found experimentally is up to 10 times between the signals for perpendicular and parallel detector orientations.

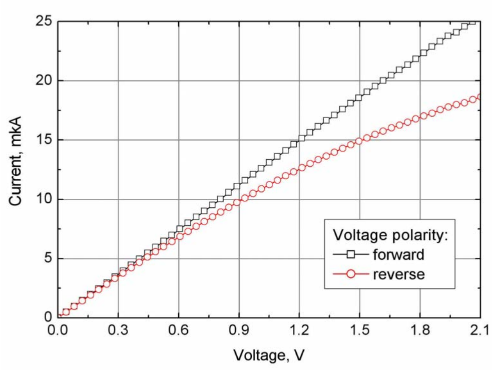


Fig. 3. Typical current–voltage characteristic of the InGaAs bow-tie detector with broken symmetry.

### III. RESULTS

The response rate of the THz detector was investigated with 500 MHz bandwidth oscilloscope. Additionally, a low-noise preamplifier was designed for easier signals readout. The main performances of the preamplifier: the impedance of signal conversion is of 100 000 V/A, the bandwidth is up to 100 MHz, and the output noise voltage is below 250 nV/Hz$^{1/2}$. The InGaAs asymmetrically shaped sample is connected to the preamplifier in the photovoltaic mode, i.e. dark current flow is canceled.

Two pulse sources of the THz radiation are involved for free-space experiments. The *first* is the optically-pumped molecular laser set to generate 433 μm wavelength (0.69 THz frequency), 0.1 ms duration, and 30 Hz repetition rate pulses. The 25 cm focal length lens is used to focus THz laser beam to the spot which waist is of about 3 mm. No other optical elements are inserted between the laser and the THz detector placed at the focal distance. The detector response to the THz laser excitation is shown in Fig. 4. The results were recorded turning slightly the length of the THz laser resonator. In this manner different longitudinal modes in the resonator were selected for the lasing. It is seen that the parameters of the THz laser pulse (rise time, duration, shape etc.) can be easily monitored at room temperature with the THz detector.

The *second* source is W-band transmitter delivering a pulse power up to 100 W. It generated a 94 GHz frequency, 300 ns duration, and 100 Hz repetition rate pulses. The THz detector was placed in front of W-band horn (see Fig. 2). No other optical elements were used in between. The radiated pulse was measured with the THz detector and, for comparison, with a fast Schottky diode. The results are shown in Fig. 5. One can see that both detectors demonstrate the same pulse shape. The rise time is found to be the same in both measurements. Therefore, one can conclude that the response time of the THz detector is not worse than 7 ns, as the rise time of the microwave source employed.

It deserves mentioning that the dynamical range extends over the 40 dB and no any negative outcome was observed after application of pulsed power reaching hundreds watts.

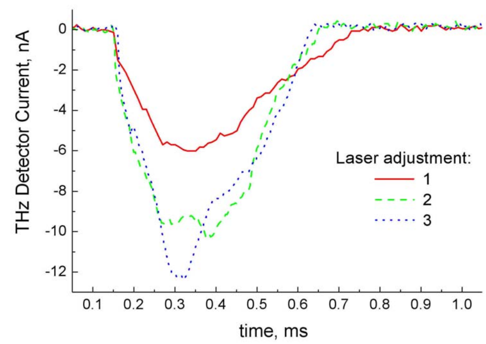


Fig. 4 The pulse shape of the THz laser adjusted for different mode lasing.

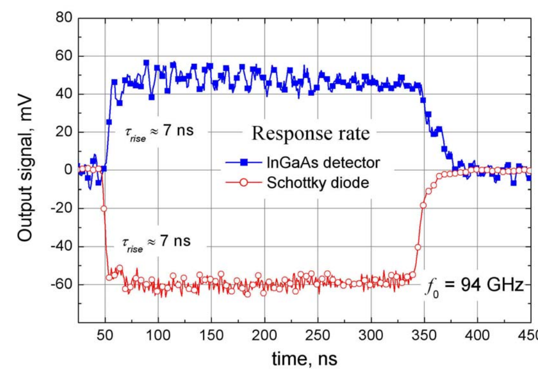


Fig. 5 An oscilloscope trace of the bow-tie InGaAs detector and fast Schottky diode radiated with a 94 GHz frequency W-band source.

### CONCLUSIONS

The response rate of a room temperature terahertz InGaAs-based bow-tie detector with broken symmetry has been experimentally investigated. The response time of the THz detector has been found to be less than 7 ns. The real value is hidden by limited possibilities of the pulse source used. It has been demonstrated that the THz detector is fast enough to record longitudinal modes beating in the optically-pumped molecular laser cavity.

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