Terahertz optical mixer design

E. F. Plinski,*[1] R. Wilk,[2] M. Mikulics[3]

[1]*Faculty of Electronics, Wroclaw University of Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw,*
[2]*Menlo Systems GmbH, Am Klopferspitz 19, D-82152 Martinsried, Germany,*
[3]*Institute of Bio- and Nanosystems, Research Center Jülich, 52425 Jülich, Germany,*

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Abstract— Terahertz sources and characterization of THz radiation are briefly reviewed. The technique of THz photomixing is described. A coherent detection method is explained.

The term "terahertz" is relatively new. It became popular in the mid 1970s, when the term "submillimeter" wave was finally substituted by a new one. Terahertz radiation occupies the range of the radio-optical spectrum between 300 GHz and 10 THz (some authors extend the terahertz spectrum to 30 THz – a CO_2 laser region), or in other terms, from 1 mm to a few tens of micrometers. Because it was not available by detection and generation methods in the past, sometimes it was called a "forgotten gap".

There are different devices to fulfill the "forgotten gap" and release terahertz radiation in a controlled way. Known and quite sophisticated are synchrotrons [1] and free electron lasers (FEL) [2]. Both systems are based on a change of the electron beam direction. In that way the acceleration of electrons is obtained. In the case of a synchrotron, electrons run around the circle, in the case of an FEL, electrons are undulated along the series of magnets creating a linear shape of the device ended at both ends with mirrors (like a laser). A similar principle can be met in BWO tubes (Backward-Wave Oscillator) on a much smaller scale [3]. In the case of synchrotrons and FELs the spectrum of output radiation covers the range from just Far Infrared (FIR) – today called THz, via IR, visible, UV, to X-ray. A BWO covers the radio-optical spectrum from millimeter waves to THz. Smith-Purcell emitters (SP) using the same principle are also used in the terahertz technique [4]. The Smith-Purcell effect as a precursor of a Free Electron Laser has been known since 1953 (an electron beam runs very closely parallel to metal diffraction grating). It is possible also to use devices popular in a microwave technology like IMPATT diodes (IMPact Ionization Avalanche Transit-Time) based on avalanche generated electrons [5] or Gunn diodes used in high frequency electronics, sometimes called transferred electron devices (TED), based on N-doped semiconductor material [6]. Another source of terahertz radiation is a FIR laser, sometimes called a submillimeter laser (today called a THz laser) [7]. The device is based on optical pumping, usually by a carbon dioxide laser. Different molecules can be used for generation of the THz. The laser is rather weakly tuned: output frequency depends on a pumping medium applied. Among semiconductor devices where terahertz waves are produced directly, Quantum Cascade Lasers (QCL) seem to be quiet perspective [8]. Another group of semiconductor THz devices create a terahertz wave using an optoelectronic switch method [9] [10]. One of the devices taken from the aforementioned group is considered in the present paper.

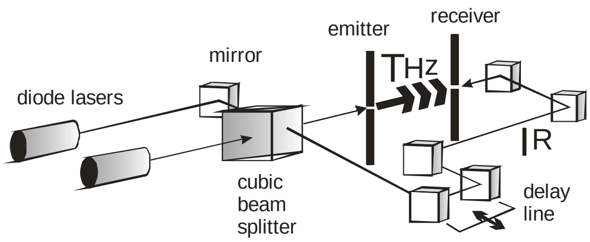

Fig. 1. The terahertz photomixer setup. The heterodyne beams from two diode lasers pump the first THz chip – emitter via a cubic beam splitter. The same IR radiation is used as a probe beam at the identical THz chip – receiver. The phase of the probe beam IR vs the THz beam can be regulated using a delay line.

An optical switch is a device which creates a change in the parameters of a semiconductor to generate carriers caused by illuminating the semiconductor with light. One of the methods is to apply a short pulse laser with a suitable energy gap as a pumping source for a suitable semiconductor. It can be molecular-beam epitaxial GaAs, grown at a low substrate temperature (Low Temperature grown Galium Arsenide: LT-GaAs) between 200 and 400 ◦C [11]. It has up to 1.5 at.% of excess arsenic, and it exhibits high resistivity (above 106 Ωcm) and high carrier mobility (appr. 6000 cm2/Vs) after annealing. Such a material is promising for the preparation of

* E-mail: edward.plinski@pwr.wroc.pl

photoelectric switches, as well as tunable sources of terahertz radiation by photomixing [12], see Fig. 1. It can generate electron-hole pairs in one picosecond. It means that it can generate terahertz radiation if we use a small antenna (a simple dipole) technologically fixed at the surface of an LT-GaAs plate. It should be coupled with desired radiation frequency, it means that the dimensions of a dipole are carefully chosen (usually a half of the wavelength). The antenna (emitter) is biased with a suitable voltage (usually between 10 V and 50 V).

The adjusting of the terahertz setup in the optical mixer arrangement usually makes many problems. We are trying to present the main problems to overcome.

The focus should be smaller at the Lt-GaAs emitter than at the receiver. That is why the lens of shorter focus (let us say, appr. 5 mm) is used at the emitter side, and longer (let us say, appr. 20 mm) - at the receiver side. The probe beam should be a bit off-focus at the receiver to cover all gap between arms of the dipole. During the experiments we can easily to exchange both lenses

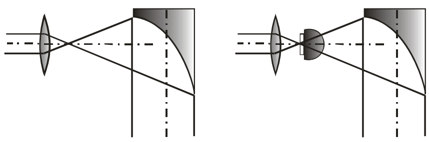

Fig. 2. Left - the lens (microscope lens) and off-axis parabolic mirror. Right – the LT-GaAs chip inserted at the focus of the lens.

without destroying the THz path (see Fig. 2).

The optical paths of the infrared, THz rays, pumping and detecting beams should be carefully equalized. The reason is accidental perturbations, which can disturb the

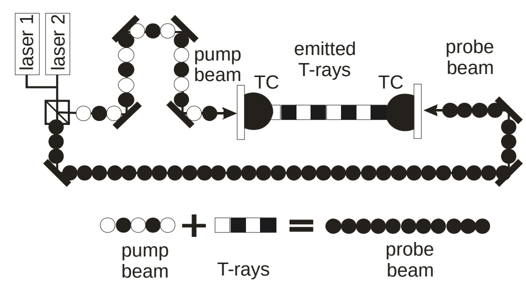

Fig. 3. The pumping beam path plus THz ray path should be equal to the probe beam path.

signal at the emitter. Perturbations should reach the detecting chip at the same time. That is why the path of the pumping beam plus the path of the THz ray path should be equal to the probe beam path with the tolerance of approximately 1 cm or even less. Fig. 3 explains the idea. The described method results in a more stable signal from the detector antenna.

The Si lens used in the THz arrangement shortens the focus of the lens "O" (see Fig. 4) used for a pumping beam from diode lasers. It is necessary to take into account the effect and try to bring the lens "O" and Si closer to the off-axis mirror, as shown in the figure above. The procedure should be repeated symmetrically at the other end of the THz path, i.e., behind the off-axis mirror

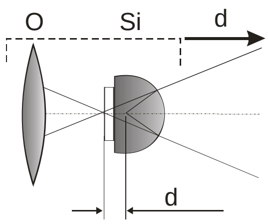

Fig. 4. The shortened focus of "d" of the parabolic mirror in the silicon lens Si. It is necessary to make some corrections and move the lens "O" together with the Si lens with a chip in the direction of the parabolic mirror by distance "d".

setup.

The LT-GaAs element should be placed ideally in the center of the Si lens, otherwise the THz beam is moved from the main optical axis and it can create many problems with adjusting the arrangement.

A typical THz photomixer arrangement is shown in Fig. 5. It consists of two LT-GaAs chips fixed to hyper-hemispherical high resistance silicon lenses. The emitting chip is illuminated with a laser beam carefully adjusted to obtain efficient heterodyning (photomixing) at the surface of the chip. If the antenna at the chip surface is biased, than carriers create periodical current in the antenna and it radiates with the heterodyne frequency. The output THz frequency can be easily and continuously changed via

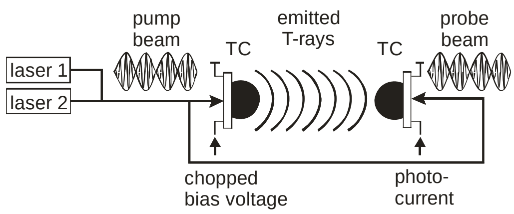

Fig. 5. The CW terahertz arrangement uses two diode lasers and two semiconductor chips TC with silicon lenses. The first chip works as an emitter, the second one as a detector.

temperature change of one or both lasers.

Fig. 6. explains the detection method in the THz photomixing experiment. When the chip is illuminated with heterodyned laser beams, then the intensity of an electric field changes the parameters of the dipole (the antenna) at the surface of the LT-GaAs plate. In other words, it increases and decreases periodically (with the

heterodyne frequency) the detectivity of an antenna. In that way a constant component other than zero is obtained. Additionally, the pumping beam is mechanically chopped to use a periodical signal for synchronous detection with a lock-in amplifier (see the figure below). Usually, the alternating bias voltage at the emitter with the frequency of a few kHz is used as a reference signal for the lock-in.

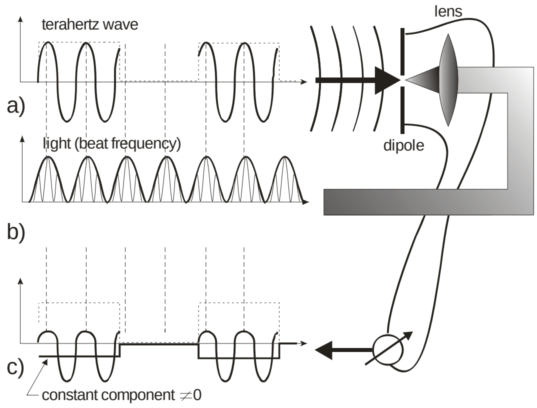

Fig. 6. The explanation of the detection method when the pumping beam is mechanically chopped (50-50%). a) chopped THz wave, b) intensity of the heterodyned beams, c) average signal (constant component) of the THz.

The production of terahertz radiation in optical mixer arrangements or, in other words, in a THz photomixer is simple and prospective. Different semiconductors can be used as a emitters and receivers of the terahertz wave. One of them is low temperature grown gallium arsenide (LT-GaAs). An elaborate arrangement of the optical mixer can be used as a CW source of terahertz radiation. The frequency of the THz source can be easily changed by controlling the temperature of the laser diodes – both or one of them. It depends on the desired beat frequency. The system can be easily used as a cw spectrometer. It can be also easily applied in imaging. Another application is space exploration [13]. A useful application is also short distance wide broadband THz communication [14].

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