# Photomixing THz Generation from Nitrogen-Ion–Implanted GaAs Metal-Semiconductor-Metal Diodes Enhanced by a Bragg Mirror


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***Abstract*—We demonstrate that a nitrogen-implanted GaAs can be successfully implemented as a tunable, THz frequency range photomixer, optimized for the best performance for optical excitation in the 760-800 nm range. The latter was obtained by fabricating a metal-semiconductor-metal diode on top of a Bragg mirror structure and resulted in a clear enhancement of the THz radiation emission in photomixing experiments.**


## I. INTRODUCTION

The development of semiconductor materials and device architectures suitable for highly efficient THz sources found in recent decades a tremendous growth as a result of a strong need especially for spectroscopy applications such as for radio astronomy, material inspection and security [1-11]. One of the representatives of such THz sources are tunable THz LT-GaAs photomixers [1-6]. The cw (continuous wave) THz generation in these devices is based on a photomixing process. Two cw laser beams with a wavelength difference corresponding to the desired frequency of the THz radiation are simultaneously focused on a mixing device characterized by sub-picosecond carrier lifetime, to assure the generation of broad frequency range THz signals. However, the efficiency of conventional materials such as the family of LT-GaAs materials has already reached its limits. Therefore, a further performance improvement of THz photomixer devices can only be achieved by alternative material systems with sub-picosecond carrier lifetime combined with an appropriate device layout designed for operation in the intended "narrow" frequency range. One such approach is the implantation of various ions, such as O, Si, Ga, As, N etc. into GaAs as was already presented in the last decades [12-17]. Furthermore, it was also demonstrated that the performance of THz photomixer structures can be improved significantly if a resonant cavity based on a Bragg mirror is applied [4].

Here, we present a THz-wavelength photomixer based on an MSM structure but fabricated it on nitrogen-implanted GaAs [12-14] and, additionally, on top of a Bragg mirror intended to enhance the device`s photoresponse. The MSM diode is integrated with a resonant dipole antenna, an RF choke and contact pads [4]. For the sake of achieving high conversion photomixing efficiency, the carrier lifetime of N-implanted GaAs was tuned to the values best suited for the pre-defined THz output frequency range, namely, 480-490 GHz, which corresponded to the resonant dipole antenna.

## II. SAMPLE PREPARATION AND RESULTS

We started the fabrication process unconventionally for the THz material "family", where MBE techniques [1-4] are mostly applied: metalorganic vapor phase epitaxy (MOVPE) [18] was used to deposit the layers on 2-inch (100) oriented semi-insulating GaAs substrates. The MOVPE technique is – in contrast to MBE - a very versatile technique which allows the deposition of many micron thick epitaxial films as well as layers down to the nm scale with precise composition control reproducibly and is therefore the preferred deposition method for industry. By applying the so-called "nitrogen" process in which nitrogen is used as the carrier gas and ambient instead of hydrogen, the efficiency is greatly improved with respect to precursor exploitation and layer uniformity allowing cost-effectiveness at the additional feature of increased process safety [18]. After depositing a 100 nm thick GaAs buffer layer, 12 periods of AlAs/GaAs 67/55 (nm) were grown serving as a Bragg mirror succeeded by 500nm of GaAs. In the following, samples were implanted with 191 keV nitrogen ions and an implantation dose of ~$8.10^{11}$ ions/cm$^2$. Subsequently implanted materials were annealed in nitrogen ambient for 10 minutes at 300°C, 350°C and 400°C. After the annealing process, photomixer structures (figure 1) were fabricated using e-beam and conventional lithography [4,6,14,17]. Our photomixing experiments were carried out by simultaneously illuminating the MSM area with two, highly stable, tunable cw laser sources with a slight, but controllable difference of their wavelengths. The output in a form of a cw THz radiation was detected using a pyroelectric detector.

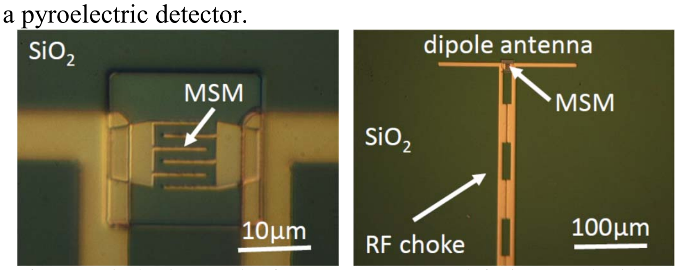


**Fig.1.** Optical micrograph of an MSM structure (left) integrated with a resonant dipole antenna and RF choke (right).

Two wavelength dependency measurements were performed [19]. The first measurement-type was done by tuning the wavelength of both lasers simultaneously, while keeping their wavelength difference fixed at 1 nm. In Fig. 2, we show our experimental results. Note that the *x*-axis in Fig. 2 represents only the wavelength of one of the laser sources. It is easy to notice that the maximum detector response occurs when the wavelengths of the two laser sources are 784 and 785 nm, respectively, corresponding to a 1 nm separation. The

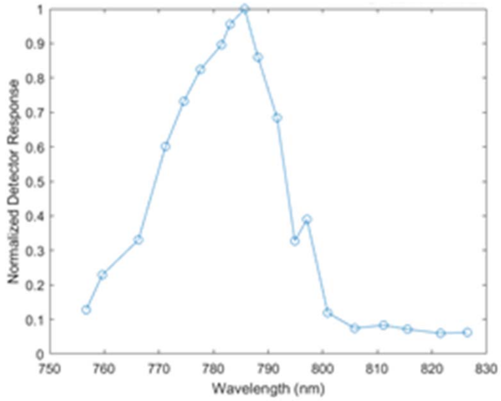


**Fig. 2.** Normalized detector response depends on the wavelength of both cw laser sources with their relative difference kept constant and equal to 1 nm. The *x*-axis corresponds to only one of the laser sources.

photomixer response dependency of the wavelength supports our reflectivity simulations of the Bragg mirror, which is underneath the photomixer [19]. The latter is a strong proof that indeed the mirror enhances the THz radiation emission.

In another case, we fixed one of the cw sources at 785 nm wavelength, while the other was tuned in the 780 – 808 nm range. The maximum pyro-detector response was observed when the wavelengths of the two sources were very close, namely, 785 and 786 nm. The latter agrees with the previous measurement and corresponded to an output THz frequency of 486 GHz, for which our dipole resonant antenna was designed to reach the maximal radiation efficiency [19]. When the wavelength of a tunable cw source was detuned by 5 nm, corresponding to the output THz frequency of approximately 2 THz, the pyroelectric detector response dropped to zero, because we were leaving the optimal range of operation of our photomixer device.

Additionally, the lifetime of photogenerated carriers in our implanted and annealed GaAs materials on top of the Bragg mirror was studied using femtosecond time resolved reflectivity measurements (figure 3). Carrier lifetimes extracted from these measurements indicate approximately similar carrier lifetimes ~ 200 fs (fast $\tau 1$ component) for all three implanted samples annealed in the range from 300°C to 400°C. On the other hand, "slow" ($\tau 2$) carrier lifetime components in the range between 1÷1.52 ps were also determined. This result confirms that the

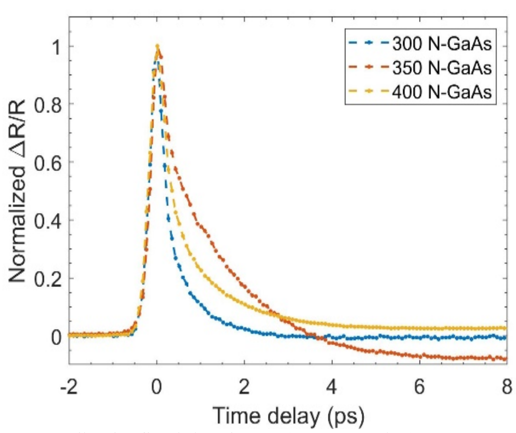


**Fig. 3.** Normalized reflectivity change (representative) measurements for N-implanted GaAs materials annealed at 300°C, 350°C and 400°C.

carrier lifetime can be tuned to the values best suited for the pre-defined THz output frequency range.

We designed and fabricated THz photomixer structures based on nitrogen implanted GaAs with an integrated Bragg mirror. The carrier lifetime was tuned successfully by the annealing process to the values best suited for the pre-defined 480-490 GHz output frequency range. Our research demonstrates that photomixers based on nitrogen-implanted GaAs materials including Bragg mirrors are very promising candidates as a source for efficient THz generation.

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