Efficient THz Source Using GaAs and InGaAs nipnip Photomixers

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Abstract: We report on efficient ballistic-transport enhanced GaAs and InGaAs nipnip superlattice CW-THz sources with a transit-time 3dB-frequency up to 1 THz and independently designable RC-roll-off. 1 μW output power at 400 GHz has been achieved.

Semiconductor photomixers are widely used to generate continuous wave THz radiation up to 1-2 THz. Two heterodyned laser beams (with optical power P_{opt}) detuned by the desired THz frequency generate an AC current I_{THz} in the semiconductor structure. This current is fed into an attached antenna (with resistance R_{ant}) to radiate at the THz-frequency according to $P_{THz} = \frac{1}{2}I_{THz}^2 R_{ant} \propto P_{opt}^2$. However, a power roll-off with increasing frequency due to the $R_{ant}C_{pin}$-time, τ_{RC}, and the transit-time, τ_{tr}, reduces the emitted THz-power with increasing frequency, each with a 3dB roll-off. State-of-the-art photomixers use P-I-N structures designed for a trade-off between transit- and RC-time. Recently, specially designed P-I-N devices have been demonstrated with a THz-power of more than 10 μW at 1 THz with a resonant antenna [1]. Modifying the structure to a waveguide device allows for a higher laser power and, therefore, for higher THz-power as demonstrated by [2] with 24 μW at 913 GHz. At the same time, we have developed a concept where the trade-off between transit-time and RC-time (which strongly reduces the THz-power at higher frequencies) can be overcome. An RC-optimized P-I-N-diode is divided into N nano-P-I-N diodes (nipnip superlattice). The i-layer of the nano-P-I-N diode is optimized for shortest transit time using quasi-ballistic transport of electrons only. This is achieved by a graded-gap i-layer, where the absorption is restricted to a small region close to the p-layer. By applying an external DC bias, the optimum field is chosen such to prevent Γ-L side-valley scattering ($eFd_i < \Delta_{\Gamma L}$). In addition, the width of the i-layer, d_i, is adapted to the desired 3dB transit frequency. The current-continuity of the structure is preserved by the np-recombination diode connecting the individual nano-p-i-n diodes. The required high (forward) current density is achieved by implementing recombination centers in the diode. A monolayer of ErAs in GaAs as well as in InGaAs has been proven to be an excellent solution. Quasi-ballistic transport in GaAs-based nipnip-photomixers has been shown for a transport length of d_i =150 nm and up to 1 THz. In the lower bandgap material InGaAs, an even more pronounced performance can be expected due to the lower electron effective mass and a higher Γ-L valley separation. Additionally, the responsivity is two times larger than in GaAs due to the smaller energy gap. For the same optical power, we get nearly twice the photocurrent and finally about a factor 3.3 times higher THz output power. In the investigated InGaAs samples an i-layer thickness of 300nm was chosen which has been expected from Monte-Carlo simulations to be sufficient for quasi-ballistic transport up to 1 THz. However, the 3dB transit time frequency was measured to be 270 GHz indicating that quasi-ballistic transport could not develop completely. Nevertheless, a THz power of 30 μW at 100 GHz and 1μW at 400 GHz at a photocurrent of 4 mA could be achieved from a two period device. Fig. 1 shows the current to THz conversion efficiency of a 4 period device with an area of 50μm^2 compared to a result from the literature [1] with a device area of only 13μm^2. The device efficiencies are comparable.

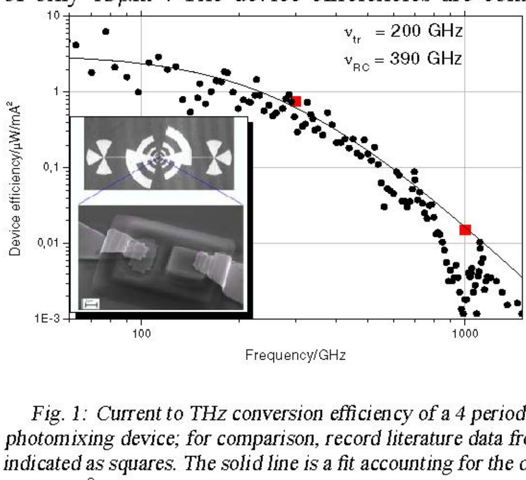

Fig. 1: Current to THz conversion efficiency of a 4 period nipnip photomixing device; for comparison, record literature data from [1] are indicated as squares. The solid line is a fit accounting for the device area of 50μm^2. The inset shows a typical device and a broadband antenna.

[1] H. Ito et al., Semicond. Sci. Technol. 20, 191 (2005)
[2] C.C. Renaud et al., Proc. SPIE 61940C (2006)