Telecom-wavelength driven photoconductors (REPHCON)

A typical interdigitated electrode structure used for photoconductors under continuous-wave operation.

Rare-earth enhanced photoconductors (DFG-project „REPHCON“)

A photoconductor is a highly resistive semiconductor that turns to a low resistance by laser illumination. For Terahertz generation, the laser signal can either be a short (<1 ps) laser pulse (pulsed operation, time domain spectroscopy), a highly multimoded laser (quasi-time domain system), or a combination of two continuous lasers that are offset by the desired THz frequency (continuous-wave operation). By using such lasers, the resistance of the photoconductor is modulated at Terahertz frequencies. A bias applied to attached electrodes results in a THz current which is subsequently fed into an antenna or radiates directly. The concept can also be used for THz detection. Instead of an applied DC bias, an incident THz field biases the photoconductor while a copy of the same laser signal that was previously used for generation of the incident THz signal is incident on the sample with a defined time delay. This way, the photoconductor mixes the THz signal and the laser signal, resulting in a rectified component that is proportional to both the laser power and the THz field.

There are five key issues a photoconductor has to fulfill:

1. The material has to be absorptive at the desired driving wavelength in order to generate sufficient photocurrent
2. The material requires a high dark resistance in order to prevent excessive heating by DC currents when used as source or to reduce shot noise when used as detector
3. A high carrier mobility is required since the current density is $j=\mu E$, where E is the applied DC or THz field.
4. In particular for receivers and for continuous-wave operation, the photoconductor requires a short carrier lifetime of the order of the THz period, i.e. sub-ps, in order to increase the resistance back to the dark resistance.
5. High break down field strength (if used as source only)

These requirements are partially conflicting. A low carrier lifetime, for instance, also reduces the mobility. Photoconductors at 1550 nm wavelength face further problems due to the small band gap (~0.75 eV) of the materials required for 1550 nm absorption. The small band gap results in a small break down field strength and low dark resistance as compared too well established 800 nm materials.

In the DFG-funded project “REPHCON”, we develop rare earth doped photoconductors for efficient THz generation (both CW and pulsed) at telecom wavelengths. For absorption, we use intrinsic InGaAs with high mobility. Quasi-metallic ErAs nanoparticles act as efficient traps for reducing the carrier lifetime. Finally, p-doping, and optional InAlAs layers ensure a high dark resistance. In comparison to other techniques, ErAs-enhanced photoconductors have several advantages: While low temperature growth (~200°C) typically deteriorates the carrier mobility, the ErAs nanoparticles are grown between 490°C and 530°C, i.e. very close to the growth temperature of InGaAs (~600°C), yielding high material quality. The position of the ErAs nanoparticles can be placed within the structure where needed by design. The size of the nanoparticles can be engineered on the monolayer level for maximizing their efficiency as trap states. The structure is therefore of very high material quality with engineerable parameters.

Large area emitters

Most photomixers are antenna-coupled in order to improve the emission efficiency. Due to a radiation resistance in the range of 20-100 Ω, the capacitance of the lumped element photomixer must be in the low fF range in order to achieve efficient operation at THz frequencies. This requires fairly small devices (cross sections typically smaller than 100 μm²). Due to heat generation and electrical saturation of the lumped element, the maximum (absorbed) optical power is limited to a P_{opt} ~ few tens of mW. Unfortunately, the emitted THz power is $P_{THz} \sim (P_{opt})^2$. In order to allow for much higher optical powers, we use a large area layout of a photoconductor as illustrated in Fig. 3. The optical power is distributed over an area with a diameter in the range of the THz wavelength, or even larger. The electron-hole pairs generated by absorption of the optical power are accelerated by the DC bias across the gap. This acceleration results in emission, in accordance with a Hertzian dipole model. In order to prevent destructive interference of currents with opposite sign from neighbouring gaps, each second gap is blocked. This way, all dipoles emit coherently like an array of Hertzian dipoles. Due to distributing the optical power over such a large area, much higher optical power levels can be used. The small radiation resistance of the large area Hertzian dipoles (typically < 1 Ω) is overcompensated by the quadratic increase of the THz power with optical power.

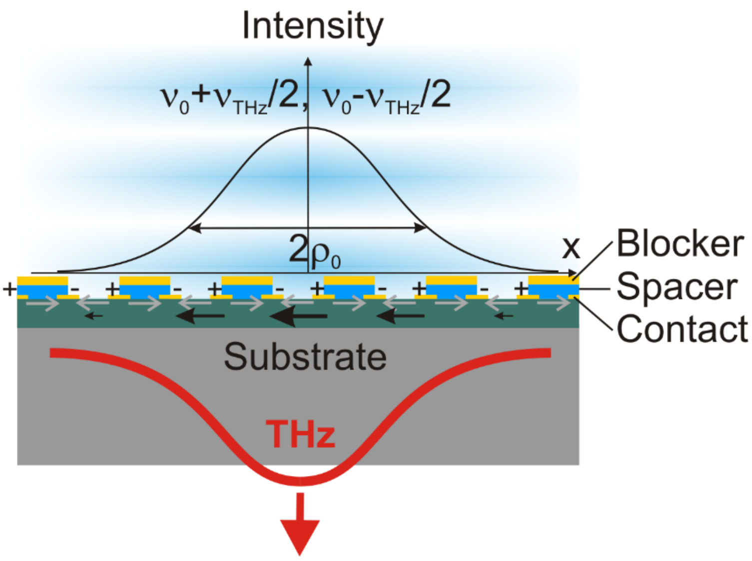

Fig. 3: Schematic of a photoconductive large area emitter. The Hertzian dipoles generated by absorption of an optical signal radiate coherently.

Fig. 4 shows the power spectrum of a first generation InGaAs large area emitter (LAE) operated at 1550 nm with a short pulse fiber laser. A dynamic range of almost 48 dB has been obtained with a ZnTe detector. The optical power incident on the emitter was limited by the laser system to 100 mW.

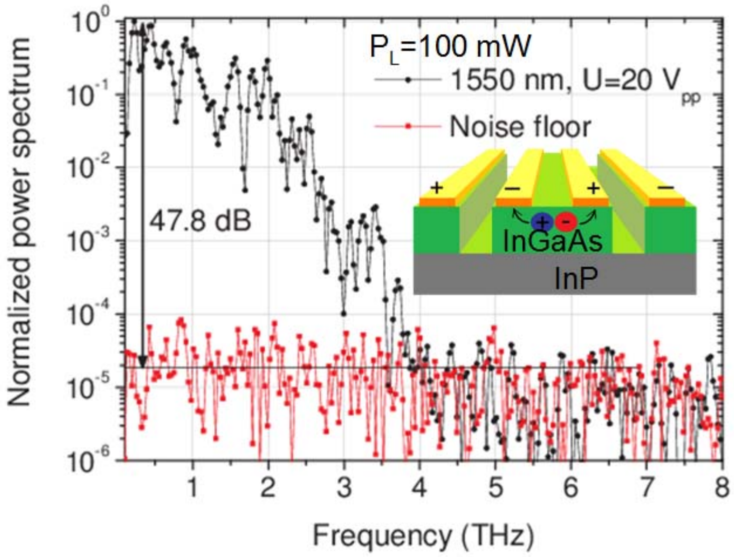

Fig. 4: THz power spectrum of a 1550 nm LAE under pulsed operation. [[Link to Paper]]()