Generating and shaping light in the THz frequency range

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With the tremendous development of ultrafast lasers we are provided with a tool for efficient wavelength conversion. Down conversion allows generation of mid-infrared and THz light and provides in addition also the ability to control the phase. This additional control knob is a new feature for optical experiments which we are just beginning to use. I will show a few experiments with semiconductor nanostructures and quantum cascade lasers where the phase information allows observing physical processes directly; this includes population transfer, amplification, and short pulse formation. In addition to the phase information, down conversion and quantum cascade lasers provide us with very large bandwidth- spanning more than one octave. Handling these bandwidths is an interesting challenge and also extremely attractive for new optical methods like frequency comb sensing.

Few-cycle THz spectroscopy is the right tool to study elementary transitions in solids. Moreover, time-resolved THz spectroscopy allows phase-locked measurements – in particular phase-resolved detection. We take advantage of this fine capability to study the dynamics of semiconductor nanostructures. Quantized transitions are very attractive for the realization of quantum devices from Quantum Cascade laser to single photon emitters. Therefore the knowledge of the relaxation and dephasing times in these structures is of upmost importance.

Furthermore, phase-resolved THz spectroscopy allows unique measurements of stimulated emission from Quantum-Cascade lasers. The knowledge of the phase of the THz emission provides fascinating insights into the quantum optical processes. In addition, these measurements enable the study of the gain band width, gain saturation and recovery.

With high intensity THz pulses we can also explore the non-linear regime of intersubband transitions. The observation of two and three photon processes is encouraging for further THz non-linear effects in structures with large confinement. In meta-material coupled nanostructures we observe strong coupling und study its dependence on the THz field strength.

When two resonant modes in a system with gain or loss coalesce in both their resonance position and their width, a so-called "exceptional point" occurs which acts as a source of non-trivial physics. Using a pair of coupled microdisk Quantum Cascade Lasers, we have shown that in the vicinity of these exceptional points the laser shows a characteristic reversal of its pump-dependence including the anomalous feature of a decreasing intensity of the emitted laser light for increasing pump power.

We report on the ultrastrong-coupling between localized modes of a planar THz metamaterial and intersubband transitions. Such a system exhibits the formation of a lower and an upper polariton branch when the metamaterial eigenfrequency is tuned close to resonance with the intersubband transition. We use THz time-domain spectroscopy to study the polariton system and observe a value of for the splitting ~20%. In addition to the usual geometrical scaling, we employ effective tuning of the metamaterial resonance by dry etching with a tuning range of more than 1 THz.

The modification of the radiative efficiency of THz meta-atoms, as the basic building blocks of a metamaterial surface will be discussed. We demonstrate the substantial influence on the radiative lifetime when the elements are arranged in densely packed super-cells. The observed change of radiative lifetime with respect to the number of meta-atoms resembles the cooperative behavior of an ensemble of excited atoms in a confined volume.

References

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