New record achieved in terahertz pulse generation

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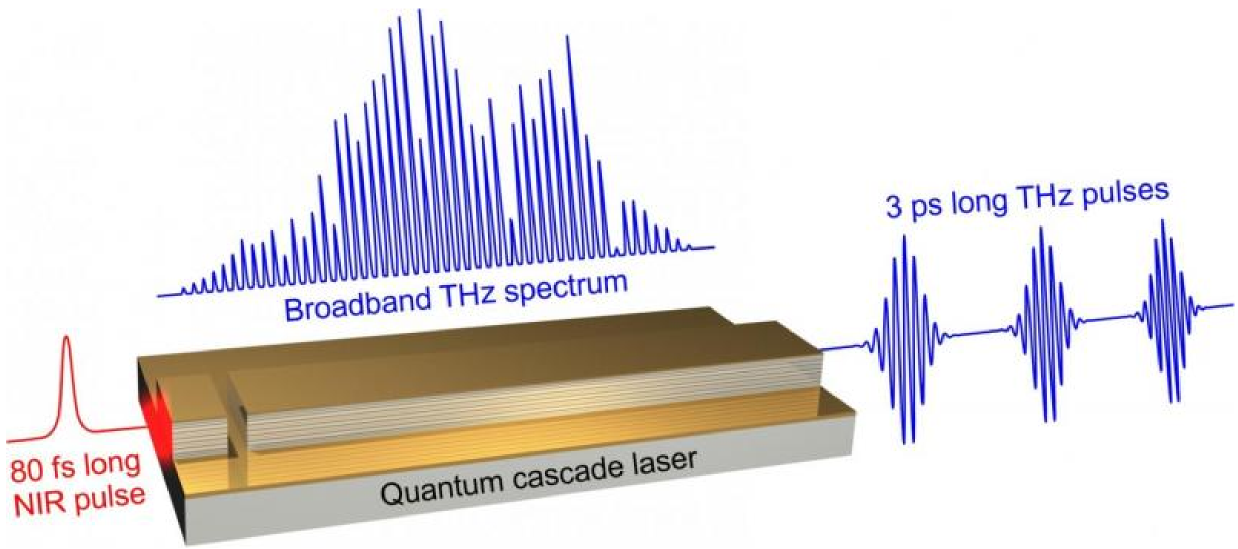

Credit: Vienna University of Technology

A group of scientists from TU Wien and ETH Zurich have succeeded in their attempts to generate ultrashort terahertz light pulses. With lengths of just a few picoseconds, these pulses are ideally suited to spectroscopic applications and enable extremely precise frequency measurements to be taken.

The unique properties of terahertz radiation mean it is of interest for a wide range of potential applications, including non-invasive medical imaging and the detection of hazardous substances. Terahertz waves can penetrate many materials that are opaque to visible light and, unlike X-radiation, do not pose a risk of damage to biological tissue. In addition to this, many substances have a molecular fingerprint in the terahertz range, allowing them to be detected using spectroscopic methods. One efficient way of generating these terahertz waves is using quantum cascade lasers, which a working group led by Prof. Karl Unterrainer at the Photonics Institute at TU Wien has been researching and developing. Quantum cascade lasers consist of a precisely defined sequence of several hundred semiconductor layers that measure just a few nanometres in thickness. This special construction means there is the freedom to select the exact energy state at which the electrons stay within the semiconductor structure. This allows the frequency of the laser light emitted to be adjusted to suit the application in question.

Creating a frequency comb with a broadband 'laser sandwich'

With this special feature of being able to determine the laser wavelengths themselves, several quantum cascade structures with different emission frequencies can be stacked on top of one another, with the aim of generating broadband terahertz radiation. "Heterogeneous active zones of this kind are ideally suited for implementing broadband terahertz amplifiers and generating ultrashort terahertz pulses," explains Dominic Bachmann from the Photonics Institute. Plus, if the discrete laser lines are linked together to establish a fixed phase relationship between the laser modes, something known as a 'frequency comb' will be created. Frequency combs make it possible to take extremely precise measurements of the absolute frequency of the light being used, which is essential for a huge number of applications. The discovery of the frequency comb more or less revolutionised optical metrology and was honoured with the Nobel Prize for Physics in 2005. Over the past four years, researchers have been working hard to generate a terahertz frequency comb using a quantum cascade laser as part of the EU project TERACOMB. Headed up by Dr Juraj Darmo from the Photonics Institute, the team of international research groups has succeeded in generating the first broadband terahertz frequency comb based on semiconductor technology.

Watching lasers at work

One method developed by the group led by Prof. Unterrainer makes it possible to analyse internal quantum cascade laser parameters during laser operation. This technique is based on time-resolved spectroscopy, with broadband terahertz pulses penetrating the sample to be measured. Based on femtosecond lasers, this technology can be used to collect the full information content relating to the time and frequency range with just one single measurement. As a result, the scientists at the Photonics Institute have managed to quantify the optical gain coefficients as well as the optical dispersion in broadband terahertz quantum cascade lasers, improving their understanding of the complex dynamics at play. "These findings allow us to increase the laser bandwidth even further and to improve the efficiency of frequency combs," explains Juraj Darmo.

Targeting losses

One unresolved issue with terahertz quantum cascade lasers had been the existence of laser lines with different propagation speeds. If there are laser modes with a higher lateral order, the intensity is distributed very unevenly between the laser lines, thereby reducing the usable bandwidth and preventing the generation of a frequency comb. In order to stop these modes from oscillating, the losses have to be increased to such an extent that they do not reach the laser threshold. By adding a tailored lateral absorber to the edges of the laser resonator, the researchers managed to suppress the higher lateral modes entirely, without having any relevant impact on the fundamental modes. The result was an emission bandwidth covering a full octave, very even mode distribution in the middle at 700 GHz, and a frequency comb with a bandwidth of 440 GHz. What's more, the lateral absorbers enable the generation of ultrashort terahertz pulses with pulse widths of less than 3 ps, which represents a new world record for terahertz pulses generated using a quantum cascade laser. "It was truly amazing to see how a relatively minor adjustment to the waveguide could bring about such a dramatic improvement," explains Dominic Bachmann, who has just finished writing his dissertation on broadband quantum cascade lasers.

More information: Dominic Bachmann et al. Short pulse generation and mode control of broadband terahertz quantum cascade lasers, *Optica* (2016). DOI: 10.1364/OPTICA.3.001087

Dominic Bachmann et al. Dispersion in a broadband terahertz quantum cascade laser, *Applied Physics Letters* (2016). DOI: 10.1063/1.4969065

Provided by Vienna University of Technology

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