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Extended Abstract

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New materials for radiation sources in the mid-infrared region

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The mid-infrared region (MID-IR) is usually considered spanning from 3 to 8 μm wavelength. This is an extremely useful region for many applications because roto-vibrational transitions of molecules lie in this region. In fact, possible applications comprise material analysis, quality control, dynamic measurements, environmental and medical monitoring applications, forensic testing, analysis of art objects, etc. Historically, laser sources in this region were bulky and did not permit the development of wide-spread applications. The situation dramatically changed in the last decades with the advent of compact coherent sources like quantum cascade lasers, which, unfortunately, possess intrinsic limitations as for output peak power and beam quality. Moreover, most quantum cascade lasers must be operated at cryogenic temperature, although room temperature operation is possible with strong performance limitations. A completely different approach for MID-IR quantum light generation is the use of doped insulating crystals as active media. Transition metals like Cr2+ and Fe+2 have already been used as dopant agents for broadly tunable pulsed emission, but the use of rare earths can widen the emission wavelength regions available and permit continuous wave (CW) emission with excellent beam quality. Another, more exotic, possibility is the achievement of polariton lasing in semiconductor heterostructures. A brief review of the state of the art and recent developments in this field will be given.

Quantum cascade lasers represent a relatively recent development in the area of semiconductor lasers. Whereas earlier mid-infrared semiconductor lasers were based on interband transitions, quantum cascade lasers utilize intersubband transitions. The photon energy (and thus the wavelength) of transitions can be varied in a wide range by engineering the details of the semiconductor layer structure. Even for a fixed design, some significant range for wavelength tuning (sometimes more than 10% of the center wavelength) can be covered with external-cavity devices.

Many quantum cascade lasers can be operated at room temperature, even continuously, although the best performance values are achieved for cryogenic cooling. The generation of short pulses with durations far below 1 ns is possible, although with fairly limited peak powers.

The main application area of quantum cascade lasers is in optical spectroscopy, for example in the form of laser absorption spectroscopy with the purpose of trace gas detection. Due to the very wide spectral coverage in combination with a relatively narrow linewidth, one can make sensitive instruments for the detection of a wide range of molecules. That is relevant in areas like environmental monitoring and medical diagnostics (e.g. for breath analysis).

It is also possible to use quantum cascade lasers for free-space optical communications with directed beams.

Before quantum cascade lasers were developed, large parts of the mid-infrared spectrum were accessed with various types of lead salt lasers. These are typically based on ternary lead compounds such as PbxSn1−xTe or with quaternary compounds like PbxEu1−xSeyTe1−y. The band gap energy, which determines the emission wavelength, is fairly small – below 0.5 eV – as required for long-wavelength emission. Unfortunately, the small bandgap energy also leads a substantial formal excitation of carriers at room temperature. Therefore, lead salt lasers generally need to be operated at cryogenic temperatures (normally well below 200 K, particularly for the longer wavelengths). They produce only low power levels (typically of the order of 1 mW), and their wall-plug efficiency is very low compared with that of shorter-wavelength laser diodes. Wavelength tuning over a few nanometers is normally possible via the device temperature.

Bottom Note: *This work is partly presented at 4th International Conference on Physics*