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Review of doctoral thesis

Periodically poled nonlinear crystals for difference frequency generation of fiber lasers

written by Ing. Yauhen Baravets

The presented doctoral thesis is focused on the methodology of generating a single-frequency optical wave in the mid-infrared part of the optical spectrum and the use of this radiation for molecular absorption spectroscopy of several substances. The main effort is focused on theoretical analysis and modelling followed by the preparation of key experimental parts, including pilot tests with final complex measurements. The work introduces the technique of differential frequency generation (DFG) based on the nonlinear mixing of radiation from two independent single-frequency lasers. Methods and experimental preparation of a set of nonlinear crystals are other important topics of the doctoral thesis.

In the introduction chapter, the author describes a summary of the present state in the field of mid-infrared lasers. There is a review of currently available knowledge, different kinds of generation of the mid-infrared radiation in the continuous working regime, and possible application of the radiation on absorption spectroscopy. This part of the work mentions particular techniques that allow achieving a broad tuning of the frequency of laser radiation in the mid-IR range. Therefore, the DFG method is also mentioned here, which appears to be very progressive.

In the second chapter, the author specifies the main objectives of his doctoral thesis and presents a basic scheme for the implementation of the mid-IR source based on the DFG method. At the same time, it specifies three main areas of methods, which the subsequent work then discusses in detail: tuneable lasers, nonlinear optical conversion, and absorption spectroscopy.

The third chapter presents a detailed theoretical analysis of the nonlinear optical interaction of two independent laser waves in an environment, which is described by a set of equations. Subsequently, a suitable type of nonlinear crystal is selected and the requirements for its parameters are determined. Calculations for three types of suitable nonlinear crystals (KTP, KTA, and LN) are presented and in particular the optimization of the DFG process with the need for periodic poling of the environment of nonlinear crystals with a certain spatial period to achieve high efficiency of the nonlinear process. Based on this optimization, research on KTP and KTA crystals is recommended at the end of the chapter.

The fourth chapter is the most extensive as it addresses key areas of research. The first sub-part is devoted to laser sources for generating the pump and signal beams for DFG technique. The effort is focused mainly on the experimental assembly of a widely-tuneable laser based on Yb-doped fibre. Several arrangements are presented and the one chosen allows the broadest wavelength tuning range with no mode-hops and achieving the narrowest possible width of the laser emission spectral line at the same time. This mentioned procedure is similar to the implementation of an Er-doped fibre laser. Attention is also paid to the implementation of power amplifier stages for both lasers because the DFG method requires considerable power of the signal and pump laser beams to achieve the effect of nonlinear mixing. In the second sub-part of the chapter, the procedure and subsequent implementation of periodically poled nonlinear crystals KTP and KTA are presented.

This is the most important part of the work and it can be stated that it was performed successfully because the author made several such crystals with periodical poling, which were subsequently used in the implementation of the DFG method. In the third sub-part of this chapter, the DFG technique and the optimization of the optical system are performed to achieve the best conversion efficiency for the idler beam output power.

The fifth chapter then successfully applies the realized mid-IR tuneable source to the absorption spectroscopy in toluene and nitrogen-ethylene vapours and proves the agreement of the course of the absorption lines with the theoretically determined in the HITRAN database. And finally, the Conclusion includes a summary of the results and their comments in clear form.

State of the reviewer to the doctoral thesis

The presented doctoral thesis is written completely in English. The form of the document fulfils all of the criteria which are placed to such work. The author presents all of the achieved results and with a very detailed description. The formal structure of the work is also clear and it corresponds with requirements generally placed to such a kind of scientific work. I found a few typos and minor stylistic shortcomings. Some figures have unnecessarily small dimensions, so e.g. Fig. 6, 33, 34 or 43 are worse readable. However, these shortcomings do not reduce the clarity of the work or the high level of results achieved.

1) Scientific relevance and topicality of the subject of the work

The presented work covers the fundamental and experimental research of the interesting area of photonics and lasers. The availability of narrow-linewidth and widely tuneable sources for the mid-IR of the optical spectrum is currently still low, while their need for spectroscopic measurements of various types of substances is growing rapidly in fields such as medicine, environmental and technological process monitoring. The results achieved in this work fully respond to these requirements and represent an important step towards the future development of mid-IR laser sources.

2) Used theoretical and experimental methods

The presented work is very extensive from a methodological point of view. However, all methods used are described in detail in terms of principle, mathematical and physical formalism, calculations and experimental design, and finally the resulting measurements.

3) Main goals and their achievement

Based on the presented work, achieved, and published results, it can be stated that the work met all the planned goals. In many cases, several supplementary experiments were performed, which contributed to the appropriate choice of procedure and therefore to the achievement of the desired results. In particular, e.g. it is a modernization of equipment for performing periodic poling of KTA and KTP crystals.

4) Achieved results and scientific contribution of the work

The results achieved by the author during the doctoral work were largely presented both in impacted journals and at prestigious foreign conferences. It is obvious that the methodology of radiation generation in the field of mid-IR radiation is very actual and the presented implementation of the DFG method with the original processing of poling of KTA and KTP crystals is unique and will have a wide impact on the research community of photonics and laser optics.

5) Questions for the author during doctoral thesis defence

a) Author uses the Master Oscillator Power Amplifier (MOPA) scheme with an optical semiconductor amplifier (SOA) for developed tuneable laser based on the Yb-doped fibre to obtain a higher output power for the DFG technique. Describe the physical principle, based on which using SOA significantly suppresses the Amplified Spontaneous Emission (ASE) background of the Yb-doped fibre based laser, as it is presented in Fig. 27.

b) Spectral emission line profiles were measured for tuneable lasers based on Er- and Yb-doped fibres. Based on these measured values, would it be possible to estimate the FWHM line width of the spectral line profile of the idler beam obtained by the DFG method? What value could be achieved?

c) Describe how the wavelength of the mid-IR laser beam generated by the DFG technique was monitored when profiles of the absorption spectra of toluene and nitrogen-ethylene vapours have been measured? What is an accuracy of the wavelength measurement?

I consider presented doctoral thesis of Yauhen Baravets as original and with good level of scientific results. I recommend this for the doctoral thesis defence. In case of successful defence, I recommend to grant title "doctor".

Brno, 5th April, 2021

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