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Optical parametric sources for the infrared/Sources optiques paramétriques pour l'infrarouge

Continuous-wave mid-infrared laser sources based on difference frequency generation

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Abstract

We report on recent developments of widely tunable, continuous-wave (CW) laser sources based on difference-frequency generation (DFG) in nonlinear optical materials. The state-of-the-art of CW DFG technology will be reviewed. Applications of the DFG-based laser source to high-resolution molecular spectroscopy and trace gas detection will be presented. New development trends of DFG will be discussed. ***To cite this article: W. Chen et al., C. R. Physique 8 (2007).***

Résumé

Sources lasers continues dans l'infrarouge par génération de différence de fréquences. Dans cet article nous présentons des développements récents de sources lasers, fonctionnant en régime continu et largement accordables en fréquence, basées sur la génération de différence de fréquences (DFG) lasers dans un milieu optique non linéaire. L'état de l'art de la technologie DFG sera passé en revue. Des applications de la source laser à DFG en spectroscopie moléculaire à haute résolution et à la détection de traces de gaz seront présentées. Des tendances récentes du développement de la technologie DFG seront discutées. ***Pour citer cet article : W. Chen et al., C. R. Physique 8 (2007).***

Keywords: Mid-infrared tunable laser source; Difference-frequency generation; Phase-matching; Laser absorption spectroscopy; Trace gas detection

Mots-clés : Source laser accordable dans l'infrarouge moyen ; Génération de différence de fréquences ; Accord de phase ; Spectroscopie d'absorption laser ; Détection de traces de gaz

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1. Introduction

Developments of tunable, continuous-wave (CW) laser sources in the mid-infrared (mid-IR) spectral region from 3 to 20 µm are of considerable interest for various applications, such as:

- *Environmental applications* that include green house gas monitoring, atmospheric chemistry, fire detection, sensing of automobile, truck and aircraft exhaust emissions, combustion-generated pollutant source monitoring, catalytic converter diagnostics, and volcanic gas emissions;
- *Industrial applications* that include industrial process control, monitoring of industrial risks, fence line monitoring of industrial plants, diagnostics of gases used in the semiconductor industry;
- *Medical diagnostics applications* that include the detection, quantification and monitoring of biomarkers in exhaled breath, glucose detection, diagnostics of ulcers and colon cancer;
- *Spectroscopic applications* in high-resolution spectroscopy, reaction kinetics studies by time-resolved spectroscopy, and in studies of environment and climate relevant processes;
- *Security and military applications* that include sensing of toxic gases and biological warfare agents, detection of explosives and fugitive emissions from illicit drug-manufacturing sites, as well as infrared counter-measurements;
- *Photonic applications* that include in particular optical frequency metrology, characterization of infrared components as well as the next generation of fiber-optics communications based on novel fiber materials highly transparent in the infrared region.

Common CW sources of coherent radiation include direct laser radiation devices (denoted as class 'A' laser sources, such as color center lasers, CO and CO_2 gas lasers, interband-transition diode lasers, intraband-transition quantum cascade lasers) and devices based on nonlinear optical process (class 'B') such as difference-frequency generation and optical parametric oscillators. Currently the most useful mid-IR CW laser sources are:

- *Color center lasers (2–3.5 µm)* [1,2]: Such lasers provide an output power ranging from a few mW to several watts with a linewidth on the order of ∼MHz. Beyond its limited spectral range in the mid-infrared, a drawback is the need for liquid nitrogen cooling of the color center crystal to minimize degradation of the color center crystal and its laser performance.
- *CO (5–6 µm) and CO_2 (9–11 µm) lasers* [3,4] offer high output powers that are advantageous in highly sensitive photoacoustic spectroscopy and industrial applications, despite suffering from line-tuned spectral tunability (lasing lines are spaced by approximately 1–2 cm^{-1} in CW mode). In order to overcome the step-tunability shortcoming of the two gas lasers, the laser radiation is usually electrooptically modulated with a tunable microwave source in a CdTe or GaAs crystal to generate laser sidebands for use in spectroscopy. This technique allows ∼50% wavelength coverage within the laser lasing range. Another approach to achieve continuous tunability has been the operation at high gas pressures, as yet only in pulsed mode [5].
- *Diode lasers* [6,7]: IV–VI semiconductor lasers span the infrared wavelength range from 3 to 30 µm with an output power in the 1 mW range at cryogenical temperatures, which involves either a cryogen reservoir or a Stirling cycle cooler. As a result of over two decades of developments, distributed feedback (DFB) or distributed Bragg reflector (DBR) lasers, and external cavity diode lasers (ECDL) achieved significant progress with respect to the spectral tunability (wide tuning of ∼100 nm, and fine tuning of ∼20 cm^{-1} have been reported), as well as to the output power (CW power of ∼0.5 W has been demonstrated) [8]. Commercially available Fabry–Perot IV–VI mid-IR lasers provide single-mode injection current tuning ranges as wide as 3 cm^{-1} and individual lasers covering as much as 200 cm^{-1} of the mid-IR spectrum by varying the sink temperature from about 80 K to about 120 K [9].
- *Quantum cascade lasers (QCL)* [10–13]: Since the invention in 1994, QCLs have become one of the mid-IR laser sources of choice at specific wavelengths throughout a wide spectral region from 4 to 12 µm. QCLs exhibit high performance characteristics in terms of operating temperature, output power, and wavelength tunability. High power (10–100 mW) room temperature CW DFB-QCLs are now commercially available for specific wavelengths within the mid-IR region of 4.3–9.5 µm with a linewidth of ∼1 MHz and continuous frequency scanning by temperature tuning of ∼10 cm^{-1} [14]. Broad spectral coverage of up to 182 cm^{-1} (@ ∼ 8.4 µm) with continuous mode-hop free tuning of ∼1.25 cm^{-1} has been recently reported using a bound-to-continuum QCL design in conjunction with an external cavity grating configuration [15].