Physics and Applications of Ultrabroadband Femtosecond Lasers in Mid-IR

N. Tolstik, V. V. Dvoyrin, D. Klimentov, R. Richter, and I. T. Sorokina

Department of Physics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

e-mail address: Irina.Sorokina@ntnu.no

Abstract: We review recent progress in ultrashort pulse generation in the mid-IR wavelength range above 2 µm directly from fiber and solid-state lasers and amplifiers, highlighting the most recent achievements in the Laser Physics Group at NTNU such as compact GHz Cr:ZnS and femtosecond lasers and Tm-fiber amplifiers that are opening new possibilities for supercontinuum and frequency-comb generation further in the mid-IR. We will also discuss a few most interesting applications that benefit from the broadband mid-IR femtosecond laser sources, focusing on gas sensing as primary application.

SUMMARY

The laser sources of femtosecond laser pulses in the mid-IR wavelength range (~2–20 µm) are particularly interesting for real life applications as they address individual absorption lines of molecules, most of which have their fundamental absorption lines above 2 µm. Until very recently the ultrashort-pulsed mid-IR laser technology has been based on optical parametric devices. Very recently two major types of lasers, femtosecond Tm-fiber lasers on one side, and femtosecond Cr-doped solid-state lasers, on another side, have been introduced (Ref. 1). Cr-doped II-VI compound materials like ZnSe or ZnS (Refs. 2 and 3) are in many respects similar to Ti:sapphire with the advantage of generating high peak power broadly tunable radiation between 2 and 3 µm, where many molecules, including water and CO_2 absorb.

The Cr:ZnSe and Cr:ZnS lasers now routinely generate sub-100 fs pulses, centered in the 2.3-2.5 µm range (Ref. 3). The Cr:ZnS laser is especially interesting as it can be pumped by an Er-fiber laser, making the system compact and versatile – a next generation fiber based laser. The pulse durations so far reach from picoseconds in the chiped-pulse mode down to 40 femtoseconds (five optical cycles), with pulse energies reaching 30 nJ, corresponding to hundreds of kilowatts peak power. With average output power of up to 2 W, few and tens of nanojoule pulse energies, Cr:ZnS laser is in every respect a mid-IR analogue of a Ti:sapphire, which has been a working horse of femtosecond technology for years.

Tm^{3+}-fiber laser – another very interesting briadband fiber laser source - operates in the 1.8-1.9 µm region, and even with tuning arrangements barely reach 2.1-2.2 µm. However, the high power and energy pulses which can be obtained from Tm-doped fiber lasers in the amplification stage, allow reaching the regime of strong Raman self-shifting. In this regime, the soliton position, which can be finely tuned by the pump power, reaches 2250 nm with up to 1.25 W average output power at up to 25 nJ pulse energy and ~200 fs pulse duration (Refs. 2 and 4). Using specialy configured seed, it is also possible to generate a smooth continuous double-peaked spectrum, covering over 500 nm bandwidth from 1,.95 to 2.5 µm with up to 6.8 W of average output power and 8 dB flatness (Ref. 4). In a supercontinuum regime, this laser becomes an all-fiber completely integrated 3.8-W source, covering the whole 1.9-3.8 µm region.

Summarizing, in this talk we will discuss recent progress in these sources, which matured to industrial level and are rapidly entering real-life. We will illustrate this on example of gas sensing as primary application that benefits from the mid-IR ultrafast fiber- and solid-state laser technology, and will show opportunities, which this technology opens up in brain research and other areas. We will discuss a few most interesting applications that benefit from the broadband mid-IR femtosecond laser sources, focusing on gas sensing as primary application. Indeed, this novel class of lasers allows accessing a very important 2–3.6 µm wavelength region, where many of the important gases (like e.g. HF, NH_3, C_2H_2, HCl, H_2S, CO_2, N_2O, etc.) have fundamental absorption lines. It also provides a natural pump source for accessing even longer wavelengths via e.g. subharmonic OPO.

ACKNOWLEDGMENTS

This work was supported by the Austrian Science Fund (P24916), the EU-FET GRAPHENICS under Grant 618086, and the Norwegian Research Council (FRITEK/191614 and NANOMAT N219686).

REFERENCES

1. I. T. SOROKINA et al., "Mid-IR ultrashort pulsed fiber-based lasers," *IEEE J. Sel. Topics Quantum Electron.,* **20**, 0903412 (2014).
2. L. D. DELOACH et al, "Transition-metal doped zinc chalcogenides: Spectroscopy and laser demonstration of a new class of gain media," *IEEE J. Quantum Electron.,* **32**, 885 (1996).
3. I. T. SOROKINA, E. SOROKIN, "Femtosecond Cr^{2+}-based Lasers", *IEEE J. Sel. Top. Quant. Electron,* **21**, 1601519 (2015).
4. V. V. DVOYRIN, I. T. SOROKINA, "6.8 W all-fiber supercontinuum source at 1.9–2.5 µm," *Laser Phys. Lett.* **11**, 085108 (2014).
5. V. V. DVOYRIN, I. T. SOROKINA, "3.8 W supercontinuum all-fiber source at 1.9-3.1 µm," in *Photonics West*, (San Francisco, 2014), p. 8961-47.