The mechanisms and limitations to ultrashort pulse emission from mid-infrared fibre lasers

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Abstract: Creating short pulses at mid-infrared (MIR) wavelengths has been an ongoing research area for several years because of the high applications potential. Most demonstrations of MIR short pulse emission from fibre lasers have focused on one of two established mode-locking technologies in ZBLAN glass fibre. The shortest pulse durations, i.e., in the femtosecond regime, result from nonlinear polarization evolution (NPE) systems but this approach requires delicate system adjustment. More simplified systems that generate picosecond pulses involve saturable absorbers (SAs) such as semiconductor saturable absorption mirrors or new classes of low-dimensional materials. This latter approach has historically received the greatest research interest because of the prospects surrounding their greater compactness and higher efficiency, especially when they are made "all fiber". More recently, interest has returned to frequency shifted feedback (FSF) as a method for MIR picosecond pulse generation because it relies on established commercially available acousto-optic modulators and tunable filters avoiding the problems associated with the reliability of novel SA materials currently under development.

The influence of atmospheric absorption on pulse formation and propagation is becoming clearer. It has been established that the overtones of water vapour absorption located in the NIR seriously degrade the pulse profile. One may assume therefore that intracavity absorption would have a significant negative impact on the formation of MIR pulses from oscillators comprising free-space sections. In the femtosecond regime this is not necessarily the case, because near transform limited femtosecond pulses have been demonstrated from MIR NPE fiber lasers, though in the Er^{3+} case atmospheric absorption lines are clearly imprinted on the resulting pulse spectrum which is thought to compromise self-starting ability. We recently demonstrated a picosecond MIR FSF fiber laser in which intracavity atmospheric water vapor absorption is clearly dominant factor on the achievable pulse duration [1]. Inspection of the field of picosecond MIR fiber laser development leads to the view that this is a near universal issue which has impacted the development of SA materials in this spectral region. As development of SAs is pushed to longer wavelengths, both in emerging solid-state sources and future chalcogenide glass fiber systems, it is imperative that atmospheric absorption be accounted for completely, as absorption due to CO_2 at around 4.2 μm should be fully anticipated to have an equivalent detrimental effect.

[1] Majewski, Pawliszewska, Jackson, "Picosecond pulse formation in the presence of atmospheric absorption," Opt. Express Vol. 29, Issue 12, pp. 19159-19169 (2021)