# Tailoring high power near-IR fiber-based CPA to the needs of saturation spectroscopy

Applications like remote sensing of Earth’s and exoplanets’ atmospheres, chemical analysis in health and environmental sciences, pollution, and greenhouse gas emission monitoring demand precise spectroscopic parametrized databases to perform high-quality data analysis. The mid-IR spectral region is especially interesting since it contains multiple fundamental molecular rovibrational transitions. However, obtaining high-precision line positions and broadening coefficients in this spectral region is challenging and therefore is a subject of ongoing research efforts. One of the obstacles on the way to determining exact transition frequency and natural linewidth is the Doppler broadening, related to a molecular motion. Several approaches allow for the measurement of Doppler-free transition linewidths and positions. Those based on cooling and optical trapping of the molecules require complicated high-cost setups and lack an opportunity for hot-bands investigation. An alternative approach to these methods is saturation or Lamb-dip spectroscopy, relaying on the depletion of the ground state of the transition of interest.

Typically, a saturation power for small molecules is in the range of hundreds of micro-Watts per absorption line, with thousands of lines in a single absorption band. Therefore, Lamb-dip spectroscopy inevitably needs a broadband tunable mid-IR light source with a total average power of several Watts and an instantaneous bandwidth of tens of nm. Moreover, since a typical linewidth of the Doppler-free transition is in order of 100 kHz, which is much narrower than the broadened transition bandwidth of 10 MHz - 1 GHz, a high spectral resolution is required. Such a high spectral resolution is unaccusable for modern scanning monochromators based on diffractive elements and Fourier Transformation Spectrometers (FTS) since it would require hundreds of meters of optical pathways. An elegant solution to reach the necessary precision would be using optical frequency combs (OFCs) – narrow equidistantly spaced frequency lines. The resolution of OFC-based spectroscopic techniques is limited by the linewidth of the single comb-tooth. The linewidth of the comb-tooth, in its turn, is defined by the stability of the laser system, or by its amplitude and phase noise properties.

Here we present a roadmap towards the mid-IR saturation spectroscopy. We start with the development of a low-noise seed laser and investigation of its mode-locking regimes [1]. Choosing the “quietest” operation state, we amplify a few-mW pulses in a three-stage chirped pulses amplifier (CPA) to 100-W level. We take care about the preservation of the low-noise properties in the CPA and match its spectral characteristics to the requirements of efficient parametric conversion. We demonstrate a possibility of the fast spectral tuning of the 100-W CPA while keeping its energetic and noise characteristics, as well as high beam fidelity [2]. Finally, we explore a possibility to saturate less intense absorption lines in an enhancement cavity build with the crystalline supermirrors [3].

1. A. S. Mayer, et al., "Flexible all-PM NALM Yb:fiber laser design for frequency comb applications: operation regimes and their noise properties," Opt. Express **28**, 18946 (2020).

2. V. Shumakova, et al., "Spectrally Tunable High Power Yb:fiber Chirped Pulse Amplifier," Photonics Res. 10, 10, (2022).

3. G. Winkler, et al., "Mid-infrared interference coatings with excess optical loss below 10 ppm," Optica **8**, 686 (2021).