Soliton absorption spectroscopy

V. L. Kalashnikov* and E. Sorokin†
Institut für Photonik, TU Wien, Gusshausstr. 27/387, 1040 Vienna, Austria

We analyze optical soliton propagation in the presence of weak absorption lines with much narrower linewidths as compared to the soliton spectrum width using the novel perturbation analysis technique based on an integral representation in the spectral domain. The stable soliton acquires spectral modulation that follows the associated index of refraction of the absorber. The model can be applied to ordinary soliton propagation and to an absorber inside a passively modelocked laser. In the latter case, a comparison with water vapor absorption in a femtosecond Cr:ZnSe laser yields a very good agreement with experiment. Compared to the conventional absorption measurement in a cell of the same length, the signal is increased by an order of magnitude. The obtained analytical expressions allow further improving of the sensitivity and spectroscopic accuracy making the soliton absorption spectroscopy a promising novel measurement technique.

1. INTRODUCTION

Light sources based on femtosecond pulse oscillators have now become widely used tools for ultrashort studies, optical metrology, and spectroscopy. Such sources combine broad smooth spectra with diffraction-limited brightness, which is especially important for high-sensitivity spectroscopic applications. Advances in near- and mid-infrared femtosecond oscillators made possible operation in the wavelength ranges of strong molecular absorption, allowing direct measurement of important molecular gases with high resolution and good signal-to-noise ratio [1]. At the same time, it was observed that such oscillators behave quite differently, when the absorbing gas fills the laser cavity or introduced after the output mirror [2, 3]. The issue has become especially important with introduction of the mid-IR femtosecond oscillators such as Cr:ZnSe [4], which operate in the 2–3 μm wavelength region with strong atmospheric absorption.

As an example, Figure 1 presents a typical spectrum of a Cr:ZnSe femtosecond oscillator, operating at normal atmospheric conditions. It is clearly seen, that the pulse spectrum acquires strong modulation features which resemble the dispersion signatures of the atmospheric lines. Being undesirable for some applications, such spectral modulation might at the same time open up interesting opportunity of intracavity absorption spectroscopy. Compared with the traditional intracavity laser absorption spectroscopy [5, 6] based on transient processes, this approach would have an advantage of being a well-quantified steady-state technique, that can be immediately coupled to frequency combs and optical frequency standards for extreme accuracy and resolution.

In this paper, we present a numerical and analytical treatment of the effect of a narrowband absorption on a femtosecond pulse, considered as a dissipative soliton. Such a treatment covers both, passively modelocked ultrashort pulse oscillators with intracavity absorbers, and soliton propagation in fibers with impurities. The theoretical results are compared with the experiment for a femtosecond Cr:ZnSe oscillator operating at normal atmospheric conditions. We prove that the spectral modulation imposed by a narrowband absorption indeed accurately follows the associated index of refraction when the absorber linewidth is sufficiently narrow.

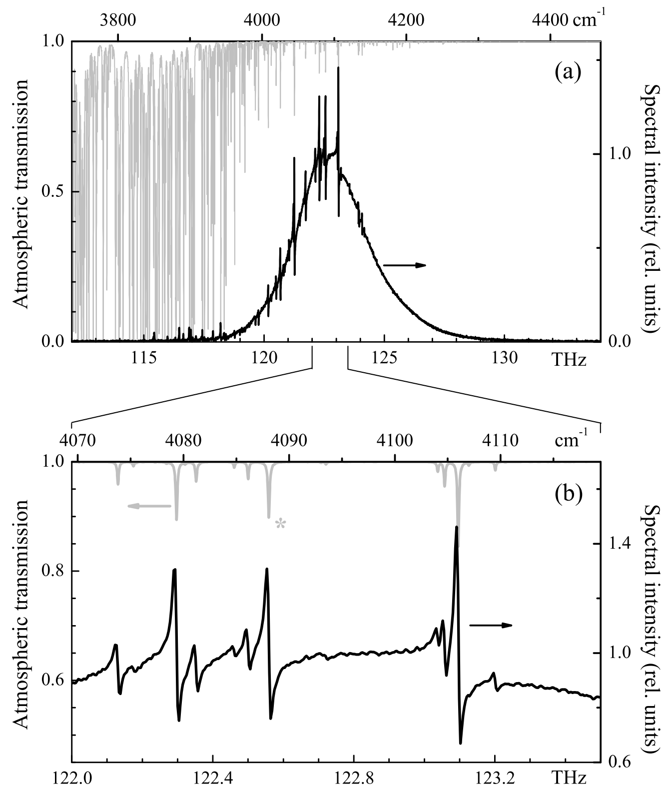

FIG. 1: Output spectrum of a 100-fs Cr:ZnSe oscillator (black solid line) when operated at open air. The atmospheric transmission (gray) is calculated from HITRAN database [7] and corresponds to a full round-trip. The lower graph *(b)* shows the expanded central part of the spectrum. Asterisk denotes the absorption line, which is used for quantitative evaluation in the last section.

*Electronic address: kalashnikov@tuwien.ac.at; URL: `http://info.tuwien.ac.at/kalashnikov`
†Electronic address: sorokin@tuwien.ac.at