

Abstract

Emission spectra of multimode lasers are very sensitive to intracavity absorption and to mode coupling in the cavity. Intracavity absorption spectroscopy (ICAS) is one of the most sensitive techniques for the detection of optical absorption. Sensitivity of ICAS corresponds to conventional absorption measurements with an effective absorption path length from a few kilometers to several thousands kilometers. Mode coupling in the laser modifies the emission dynamics and reduces sensitivity of the laser to intracavity absorption.

Diode pumped multimode solid-state lasers and especially fibre lasers are very useful for the construction of compact and sensitive ICAS-spectrometers. The present work deals with the investigation of the emission dynamics of various solid-state lasers, with the identification of the dominant mode coupling in these lasers and with the determination of the sensitivity limitation to intracavity absorption.

The most important mode coupling in solid-state lasers is found to be spatial inhomogeneity of the laser gain in longitudinal and azimuthal directions. This coupling results in low frequency fluctuations of the laser emission in individual longitudinal and polarization modes and in the modification of the emission spectrum. Experimentally this coupling has been studied with lasers, where only few laser modes are excited and the modifications are the most pronounced. It was found that the strength of mode coupling and the sensitivity of the laser emission to intracavity absorption can be controlled by the number of oscillating laser modes and by the pump power. With an 8-meter long Nd-doped fiber laser the number of oscillating modes has been increased to 50,000 and in this way the sensitivity of ICAS has been increased to more than 100 km.

Spontaneous emission becomes the main factor limiting the spectral sensitivity of the multimode lasers to intracavity absorption if the cavity loss is large and if the laser operates not far above the threshold. The influence of spontaneous emission on ICAS has been observed by measuring strong absorption lines of water vapour in the cavity of Nd- and Yb-doped fibre lasers. The influence of spontaneous emission in these lasers is especially pronounced due to the presence of strong relaxation oscillations.

Lasers with inhomogeneously broadened spectral gain, such as fibre lasers, additionally show the dependence of the sensitivity of ICAS on the absorber linewidth. The emission spectrum of the laser is very sensitive to intracavity absorption, if the absorptive linewidth does not exceed the homogeneous linewidth of the gain. If, however, the absorptive linewidth is larger than the homogeneous linewidth of the gain, the sensitivity drops significantly. This phenomenon has been measured with Nd- and Yb-doped fibre lasers.

Depending on laser parameters one or several of the above mentioned features can be dominating factors limiting the spectral sensitivity of ICAS. The results obtained in the present work show that the sensitivity of intracavity absorption measurements can be increased by using the active media with broad spectral gain, selecting one polarization mode only, applying smaller pump rates, reducing cavity losses, increasing the cavity length and reducing the length of the active media.