Abstract

Rare-earth-doped glasses represent a cornerstone in photonics, enabling versatile applications from telecommunications to medical devices through tailored emission and amplification properties across near- to mid-infrared wavelengths. In particular, they are essential in advancing optical telecommunications, enabling high-capacity data transmission through amplification and lasing technologies. This thesis investigates the potential of multi-ion co-doping strategies to achieve ultra-broadband optical performance, focusing on ytterbium, erbium, thulium, and holmium ions in a germanate host pumped at 980 nm. By elucidating the physics of light generation, the work addresses key challenges in broadband amplification and spectral homogeneity and efficiency, leveraging complex energy transfer mechanisms to merge emission bands of erbium, thulium, and holmium, spanning from 1450 nm to 2150 nm.

A comprehensive numerical model, based on eleven rate equations, is developed to simulate population dynamics, spontaneous emission spectra, gain profiles, and pump noise transfer functions. Optimization studies start from the bulk glass scenario, investigating the interaction between different ions and the glass behavior. The model further demonstrates noise filtering effects, where erbium, thulium, and holmium exhibit low sensitivity to pump fluctuations due to cascaded transfers, promoting stable operation in ASE sources and amplifiers. Extending to fiber amplifiers, the aim is to simultaneously amplify the standard C-band plus an additional band from 1800 nm to 2040 nm. The additional band is located in the region where HCFs have the lowest theoretical losses. The optimized configuration enables 24 THz gain bandwidth, supporting 240 channels with 100 GHz spacing with a minimum gain of 17 dB and noise figures below 3.2 dB. With a 50 GHz spacing the amplifier can support up to 480 channels. This result has been obtained with a single quadruply-doped fiber amplifier, without any gain flattening system and no channel separation. With more amplification stages and a gain flattening control, the amplifier has the potential to reach even higher gain values and a flat profile. Using the optimized concentrations, the doped glass has been fabricated by another research group, ready to be tested to further develop the amplifier. These findings highlight the potential for integrated multi-band operation in telecommunications, addressing the escalating demand for high-capacity optical networks amid surging global data traffic. Applications space in many fields other than telecommunication, such as sensing, medical lasers, and space systems, paving the way for efficient, stable optical technologies beyond conventional silica limits.