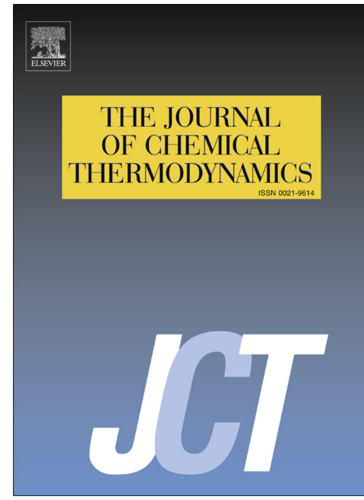

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Investigation of structural environment and chemical bonding of fluorine in Yb-doped fluorosilicate glass optical fibres

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Abstract

Fluorosilicate glass optical fibres are interesting hosts for rare-earth ions. When doped with ytterbium, for example, such fibres exhibit unique and beneficial fluoride-like spectroscopic features despite the host being predominantly silica. This work investigates the thermo-physical and chemical properties of Yb-doped fluorosilicate optical fibres in order to gain insight into the local structure about the rare earth and better understand the origins of their spectroscopic properties. Experimental findings, which suggest that the rare earth is embedded in a fluorine-rich environment in the fluorosilicate glass, are corroborated using molecular dynamic simulations.

Introduction

Even before the first studies of core/clad glass fibres as potentially practical means for high-speed and bandwidth communications [1], rare-earth doped fibres were being proposed and studied as lasers and optical amplifiers [2,3]. The steady development of low loss fibres and communication systems through the 1970s and early 1980s led to the invention of the erbium doped fibre amplifier (EDFA) in 1986 [4]. Ever since, rare earth doped optical fibres have enjoyed global attention for a variety of applications ranging from said optical amplifiers [5], to infrared light sources [6], to high power fibre lasers for defence and machining applications [7].

This later application is especially interesting from a materials perspective since the continued scaling of laser output power from a glass fibre presently is limited by a series of parasitic optical nonlinearities including stimulated Brillouin and Raman scattering (SBS and SRS), nonlinear refractive index (n_2)-related wave-mixing phenomena (e.g., four-wave mixing), or thermally-driven transverse mode instabilities (TMI) [7,8]. Although weak at low laser powers, these effects become highly problematic once threshold power levels are exceeded [9], and lead to lower performance or catastrophic failures of the optical systems in which they are employed.

Recently, a unified materials approach (as opposed to a fibre waveguide design approach) was demonstrated as an effective means to alleviate these aforementioned optical nonlinearities [10–13], in which the glass composition plays the dominant role in mitigating performance-degrading nonlinearities. When doped with ytterbium, these silica (SiO_2) clad, strontium fluorosilicate core optical fibres [14,15] were additionally found to exhibit fluoride-like spectroscopic properties such as longer upper state lifetime, lower absorption and emission cross-sections and quantum defect, relative to more conventional laser fibres [15,16]. This was despite having core compositions principally composed of silica (80 – 85 mole percent). Unequivocally, fluorine primarily contributes to the enhancement of rare-earth (RE) spectroscopic properties, and, therefore, it becomes critical to better understand its role on the glass structure and the local environment of the RE.

Accordingly, this work aims to understand the glass composition/structure of such intrinsically low nonlinearity and quantum defect ytterbium doped alkaline earth fluorosilicate optical fibres and how said structure correlates with the Yb spectroscopic properties. More specifically, this work provides insight into the effect of fluorine on the glass thermochemistry and structure, and its effect on the glass properties.