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Numerical study on the dopant concentration and refractive index profile evolution in an optical fiber manufacturing process

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Abstract

The index of refraction is an important property of optical fibers, since it directly affects the bandwidth and optical loss during information transmission. The refractive index is governed by the dopant concentration distribution across the fiber cross section, which is strongly influenced by the processing conditions. An understanding of the effects of process parameters on the dopant concentration profile evolution is important to design the drawing process for tailored refractive index and optical transmission characteristics. Although the heat and momentum transport in optical fiber drawing have been studied extensively, little has been reported in the open literature on dopant concentration and index of refraction profile development during processing. This paper presents a two-dimensional numerical analysis on the flow, heat and mass transfer phenomena involved in the drawing and cooling process of glass optical fibers using a finite difference approach based on primitive variables. The effects of several important parameters are investigated in terms of nondimensional groups, including: fiber draw speed, inert gas velocity, furnace dimensions, gas properties, and dopant properties on the flow, temperature and dopant concentration distribution.

Keywords: Optical fiber; Fiber drawing; Fiber cooling; Refractive index; Dopant diffusion

1. Introduction

Optical fibers, both multimode and single mode, are critical media for transmitting light signals used as information carriers in the communications industry. For multimode fibers, the two basic parameters governing the transmission behavior of the waveguides are fiber core diameter and core refractive index profile. The refractive index profile must be carefully controlled in order to achieve its optimal information carrying capacity [1]. For single mode fibers, cladding diameter is also an important parameter, and a minimum value must be maintained to avoid excessive losses [2]. The refractive index of optical fiber is modified by doping pure silica (SiO_2) with materials such as oxides of germanium, phosphorous and boron. Germanium (Ge) and phosphorous (P) increase the refractive index of SiO_2, while boron (B) decreases it. Since a fiber can guide light only if the refractive index of the core is higher than that of the surrounding region, most fibers consist of a cladding region of pure SiO_2 and a core doped with GeO_2 or P_2O_5 to increase its refractive index, while in some fibers the core is pure SiO_2 and the cladding is doped with B_2O_3 to decrease its refractive index.

The manufacturing process for optical fibers involves preform fabrication, optical fiber drawing, cooling and coating. The preform is preferentially made by the so-called modified chemical vapor deposition process, which includes the deposition of dopants within a fused quartz glass tube by oxidation of gaseous halides at temperatures of 1700–2100 K and subsequent collapsing of the tube into a rod [3]. The preform is then heated to above its melting temperature, while an axial tension is simultaneously

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