THERMO-INDUCED LONG-PERIOD FIBRE GRATINGS

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ABSTRACT

A new technique for long-period fibre grating fabrication using thermally activated diffusion of a core dopant to the cladding region has been proposed. Gratings written in a nitrogen-doped fibre with the help of a CO-laser or an electric arc have exhibited an excellent resistance to a thermal decay.

INTRODUCTION

Long-period fibre gratings (LPFG) [1] are the promising candidates for different applications in fibre optic communications [2] and fibre sensors [3]. In this type of gratings a resonant coupling of the fundamental HE_{11} and the cladding HE_{1m} (m>1) modes occurs making possible to create wavelength selective fibre elements. Usually the photoinduced LPFG are written in the fibre core by powerful radiation of UV-lasers using step-by-step [4] or amplitude mask [2] techniques. However, only limited number of fibres such as highly GeO_2-doped or specially photosensitised are suitable for effective UV-processing, whereas the demands for gratings in another fibre types increases.

In Ref. 5 a LPFG with a periodical deformation of the fibre core was prepared by a two-step method consisting of the creation of periodic v-grooves on the fibre surface followed by the annealing in an electric arc. The v-grooves were created by the local ablation of the cladding material using a pulsed CO_2-laser. This technique can be applied to any fibre but leads to disturbance of the fibre geometry decreasing its mechanical strength.

A unique possibility for the LPFG formation arises from the creation of the fibres doped with the chemical elements having a high diffusion coefficient in silica glass [6]. In such fibres the periodical perturbations in the core/cladding interface can be easily created by local heat treatment.

In this work, for the first time to our best knowledge, we report on a LPFG fabrication technique using a thermally activated diffusion of a core dopant to the cladding region. Owing to a relatively small atomic weight nitrogen, as a core dopant increasing

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a refractive index, expected to diffuse rapidly in silica cladding at elevated temperatures. That's why nitrogen-doped fibre is very suitable for this method of grating preparation.

The basic idea of our method is to form LPFG by local heat treatment of the fibre with shaped beam of a CO-laser or electric micro-arc discharge as a power source. Since thermo-activated diffusion of nitrogen can be effectively initiated only at rather high temperatures (~1400 ÷ 1600°C) these gratings are expected to be much more temperature resistant in comparison with conventional photoinduced ones.

EXPERIMENT

LPFGs were written in a step-index nitrogen-doped silica fibre, prepared by the SPCVD technique [7]. The fibre parameters were as follows: core/cladding index difference - 0.012, cut-off wavelength - 0.92 μm, cladding diameter - 120 μm. To heat the fibre locally up to the temperature at which the nitrogen diffuses efficiently, we used CW CO-laser (fig.1a) or an electric arc (fig.1b). The laser beam was focused by a cylindrical lens with the focal length of 60 mm giving the beam waist of 80 μm × 1.3 mm along and across the fibre axis, respectively. A typical laser intensity of about 800 W/cm² and exposure time of 1 s were applied to provide the diffusion.

The laser light wavelength of 5 ÷ 6 μm corresponds to the absorption coefficient of silica between 70 and 200 cm⁻¹. This allows one to achieve a homogeneous temperature distribution across the fibre. The exposure time and the grating period were controlled by the computer via a beam shutter and a step-motor translator.

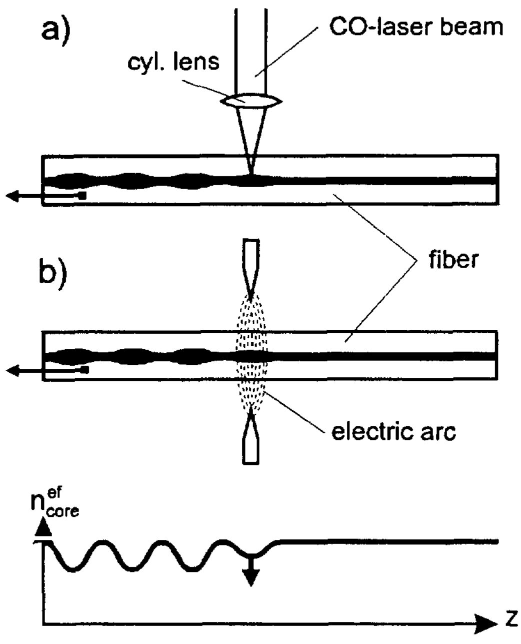

Fig.1. Experimental setup for long-period grating preparation with the help of a CO-laser (a) and an electric arc (b).

In case of the electric arc as a power source for fibre heating, the discharge parameters were optimised in order to restrict the fibre section being heated. The heating length estimated using optical microscope was about 100 μm in both heating sources. This allows us to produce the gratings with a period of more than 200 μm.

RESULTS AND DISCUSSION

The transmission spectra of long-period gratings with a period of 250 μm and a length of 25 mm written by the CO-laser and the arc are shown in fig.2. These spectra exhibited five transmission dips corresponded to the coupling of the fundamental (HE_{11}) and the cladding modes (HE_{14} - HE_{19}) in measured wavelength region. The dips' positions are similar for both types of heating, that can be attributed to the similarity of thermo-induced changes in the refractive index profile of the fibre. As seen from the comparison of dotted and solid curves in fig.2, the laser-written grating is much more uniform than the arc-produced one. This can be explained by the arc discharge instability during grating writing. Using the coupled mode theory and neglecting the influence of nitrogen diffusion on the propagation constants of the cladding modes we calculated the diffusion-induced change of an effective refractive index of the core mode. This value is 3.6×10^{-4} for the laser-produced grating plotted in fig.2. For the grating prepared by the arc it was difficult to calculate the magnitude of index change precisely because of the peaks broadening.

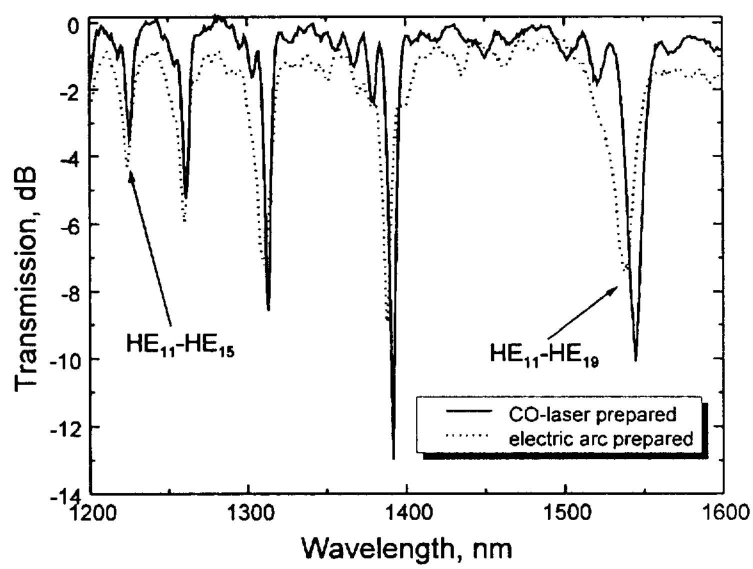

Fig.2. Transmission spectra of long-period gratings prepared in an N-doped fibre by a thermo-activated diffusion.

To find out the thermal resistance of the grating we measured its annealing behaviour in comparison with a conventional LPFG UV-written in a Ge-doped fibre. The photo-induced grating had the parameters similar to those of the thermo-induced one. The amplitude of the resonance peaks was measured during the isochronal annealing with 5 min holding at each temperature using the temperature step of 100°C. The HE_{11} - HE_{18} peak intensities versus temperature for both grating normalised to their initial values are shown in fig.3. As seen the thermo-induced grating withstands the temperature of more than 1200°C whereas the peak of photoinduced LPFG experiences 3 dB decay already at ~600 °C.

CONCLUSIONS

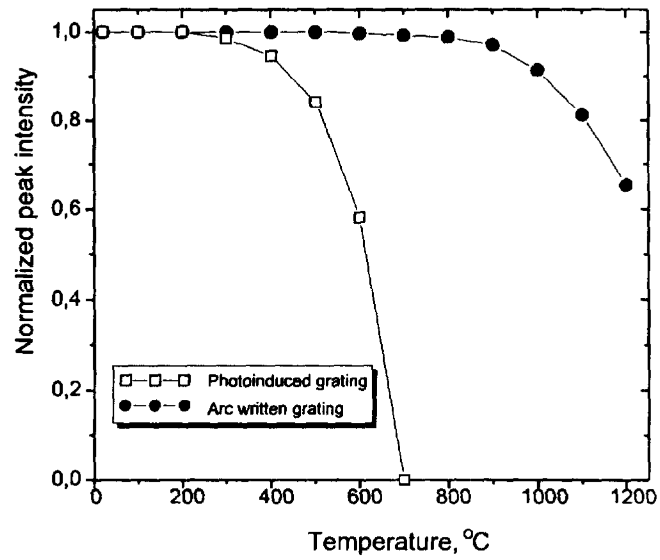

Fig.3. The dependencies of normalised peak intensities on the temperature at the isochronal annealing of long-period gratings, written by UV-light and electric arc.

A new effective way to fabricate long-period fibre gratings without using UV-sources of radiation has been proposed and experimentally realised for nitrogen-doped-core silica fibre. This technique is based on the thermal induced broadening of the refractive index profile in the fibre core owing to the diffusion of nitrogen to the cladding region. Such gratings were shown to be very stable to thermal decay and therefore can be used in various high temperature applications. The proposed method appears to be applicable to any fibre with a highly diffusive dopant used for the index shaping.

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