Direct inscription of fiber Bragg grating by high power femtosecond pulse laser

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A fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length. In recent years, FBG became important component for optical communication and optical fiber sensor system for its unique and useful properties. Here, in this work, we report the direct inscription of fiber Bragg grating by high power femtosecond pulse laser. This method requires neither photosensitive fiber nor phase mask, so it allows the inscription fiber Bragg grating into standard fibers and offers more flexibility in the choice of the structure of fiber Bragg grating.

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1. Introduction

In recent years, the laser processing technology has rapidly developed and began to replace conventional mechanical processing. Now, it is considered an essential technique widely used in high-quality components such as semiconductors, electronics, automobiles, and mechatronics. Among them, femtosecond laser inscription technique in transparent material has attracted considerable interest, which can be applied to target various materials, such as bulk glass, optical fiber, crystal and ceramic. The inscription mechanism for femtosecond laser is based on nonlinear absorption, so it is possible to overcome the diffraction limit that would not be achievable with linear absorption processes.

Meanwhile, fiber Bragg grating (FBG) is an important element in many applications including filters and dispersion compensators in fiber optic systems. Until now, conventional FBG has been fabricated by inscribing periodic variation of refractive index into the core of optical fiber using an intense ultraviolet (UV) light sources with the periodic pattern given by interference or phase mask. However, this method requires photosensitive fiber that requires extra complicated treatment into fiber core, such as hydrogen loading or B/Ge co-doping, which leads overall cost increment. Here, we report the direct inscription of FBG using high power femtosecond pulses. This method does not require phase-mask, so it offers remarkable technological flexibility. The gratings can be produced in commercial, non-photosensitised, and unhydrogenated fibers.

2. Direct inscription of fiber Bragg grating by femtosecond pulse laser

As described above, the characteristics of femtosecond laser pulses are well-suited for fabrication of FBG with direct inscription method. In femtosecond direct inscription process, each period of the grating is fabricated with one femtosecond laser pulse that is focused into the core of fiber. By moving stage with well controlled speed, one grating period is inscribed after the other at the laser pulse repetition rate. This processing method has several advantages compared to conventional method that use UV light and phase mask [1]. First, it offers flexibility in the choice of the structure of fiber Bragg grating. By adjusting repetition rate of femtosecond laser and speed of the stage, it is possible to control period of the grating easily. Second, fibers no longer need to be photosensitized with doping materials or by hydrogenation to permit FBG writing. Extremely high index modulations can be achieved without special doping for high-peak power of femtosecond laser. Thereby the femtosecond inscription technique can be used in standard optic fiber, as well as possible for all types of fiber even plastic and ceramic materials.

The schematic diagram of the FBG fabrication system is shown in Fig. 1. This system is composed of two parts, femtosecond laser part and stage part. As femtosecond laser, the ytterbium-doped fiber laser is used for system compactness and high reliability. Repetition rate is controlled by acousto-optics modulation (AOM) from 1 MHz to 50 MHz and intensity is controlled by pump laser diode power in amplifier from 0 to 10 W. A grating compressor can control pulse duration in the range from 200 fs to 20 ps. The stage is driven by a pico-motor and has high resolution of 30 nm.

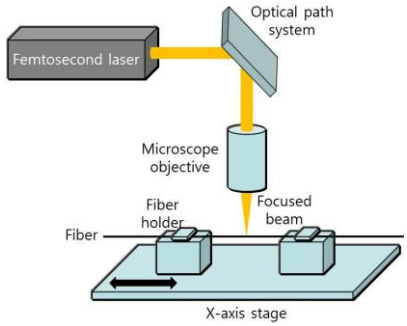

Fig. 1 Diagram of the FBG fabrication system

3. Theoretical analysis

The operation of fiber Bragg grating is based on the reflection of light from grating fringes and coupling of the modes. In a single mode fiber Bragg grating, the coupling occurs between the forward and backward propagating fields of the same mode. So, coupled-mode theory is a good tool for obtaining quantitative information about the fiber gratings [2]. In Fig. 2(a), the power reflectivity spectrum of uniform fiber reflection gratings is simulated for different index difference (Δn) values.

(a) (b)

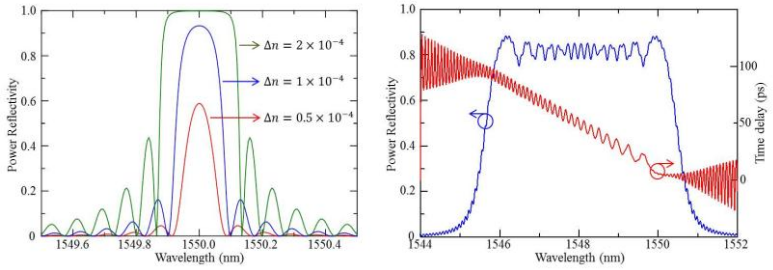

Fig. 2 (a) Power reflectivity spectrum of uniform fiber reflection grating. L=10mm (b) Power reflectivity and group delay spectrum of a chirped fiber Bragg grating. L=10mm, $\Delta n=5x10^{-4}$, grating period range : 530.82nm~529.12.nm

The reflection band can be broadened by increasing the index difference. And it can be more broadened in chirped FBG (Fig. 2(b)). In chirped FBG, it is possible to compensate chromatic dispersion for its negative dispersion property. So, a chirped FBG can be used as a dispersion compensator and light reflector.

4. Conclusions

In conclusion, we report the direct inscription of fiber Bragg grating by high power femtosecond pulse laser. This method requires neither photosensitive fiber nor phase mask, so it allows the inscription fiber Bragg grating into standard fibers and offers more flexibility in the choice of the structure of fiber Bragg grating. We construct FBG fabrication system that is composed of high-power femtosecond laser and high-resolution stage. And theoretical analysis using numerical simulation is carried out for the FBG design.

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