Non-adiabatic silica microfiber for strain and temperature sensors

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Abstract

A non-adiabatic silica microfiber is proposed for displacement or strain and high temperature sensing for the first time. The spectral response of the microfiber depends on the difference of the effective refractive indices of the core and the cladding modes, which induces resonant wavelength shift against the strain and temperature. It is observed that the peak wavelength of the transmitted comb spectrum is blue-shifted against displacement at a rate of 4.2 pm/μm. The temperature sensitivity of the device was measured to be 12.1 pm/°C with an excellent linearity for temperature measurement up to 800 °C.

1. Introduction

The applications of optical fiber sensors in biological, chemical and environmental industries have attracted great attention. These include sensors used in the measurements of liquid level, refractive index (RI), temperature, strain and others [1–3]. Compared to alternative techniques that are based on mechanical and electrical properties, the optical fiber sensors have many advantages, such as electromagnetic immunity, resistance to erosion, high sensitivity and possibility to be used in explosive environment. Currently, fiber Bragg gratings (FBGs) [4,5] are probably the most commonly used optical sensor for temperature and strain. However, developing sensors with FBGs often requires special fibers, hydrogen loading, cumbersome grating writing equipment, working with toxic gases and post fabrication treatments.

Recently, microfibers have attracted great attention because of their low loss, large evanescent fields, strong confinement, configurability, and robustness [6,7]. As such, they are expected to be useful in a wide range of fields from telecommunications to sensors, and lasers [8–10]. Microfibers may be divided into two distinct categories which are adiabatic and non-adiabatic. A microfiber is considered adiabatic if a large portion of the power remains in the fundamental mode (LP01) and does not couple to higher order modes as it propagates along the microfiber. To avoid coupling between the fundamental and higher order modes, the microfiber local length scale is designed to be so much larger than the coupling length between these two modes. In other words, the relative local change in the taper radius has to be very small (small taper angle) [11]. It has also been shown that non-adiabatic fiber tapers with an abrupt change in taper angle can be made so that coupling occurs primarily between the fundamental mode of the un-tapered fiber and the first two modes of the microfiber waveguides (LP01, LP02), where due to the large difference of the RIs of air and glass, the microfiber normally supports more than one mode. The light propagates at the air-cladding interface of the microfiber’s waist region, in which case the single-mode fiber (SMF) is converted to a multimode fiber (MMF). The result of back and forth coupling between the single mode of the fiber and the two (or more) modes of the microfiber is oscillations in the spectral response of the microfiber, which results in the transmission versus wavelength showing a periodic behavior [12].

In this paper, a non-adiabatic microfiber is demonstrated for the first time to our knowledge for strain or displacement and high temperature measurements. The microfiber is fabricated from a standard SMF using flame brushing technique. The strain and temperature sensitivities originate from the difference in the effective refractive index of the core and the cladding modes, which induces resonant wavelength shift against the strain and temperature.

2. Fabrication and experimental details

We fabricated our fused non-adiabatic microfiber, which was essentially bare standard silica single mode fibers (SMFs) by brushing heat from a butane-oxy flame across a narrow region of a