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An all-fiber scanning interferometer with a large optical path length difference

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Abstract

This paper describes the design of an all-fiber scanning interferometer. The main component of the system is a thermoelectric cooler that can rapidly heat or cool several meters of optical fiber. Over 4 cm variation of optical path length is achieved with a scanning speed exceeding 12 mm/s. The system does not include any moving parts and has low insertion loss.

Keywords: Interferometers; Fiber measurements; Sensors; White-light interferometers; OCT; OCDR

1. Introduction

Scanning interferometer is an optical interferometer with tunable optical path length difference (OPD). Interferometers with widely and rapidly tunable OPD represent an essential building block for a variety of measurement systems such as fiber optic low-coherence sensors, optical coherence domain reflectometers, optical coherence tomography systems, optical device test and measurement systems, Fourier transform spectrometers, etc. Fiber-compatible, robust and cost-effective scanning interferometers are therefore an important part of modern optical instrumentation. At present, most of the common scanning interferometers are based on bulk-optics [1] design with mechanical scanning. Such designs achieve

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considerable OPDs, but they suffer from susceptibility to environmental noise (i.e. vibration), lack of robustness, limited scanning speed, considerable insertion loss and relatively high cost. This limits their practical use to more controlled environments such as laboratories. Piezo-electric fiber-based resolvers [2] are fast, fiber-compatible and more robust. However, the maximum induced OPD is shorter, they require high operating voltages and their characteristics tend to change with time and temperature. Linear CCD array-based systems [3] are also successfully used for scanning of shorter path lengths. However they are difficult to design for larger OPDs and high resolution. In addition, they are relatively expensive devices in the range of wavelengths where Si-based CCD arrays cannot be used.

This paper presents an alternative approach that is robust, free of moving parts, can achieve large OPDs and is based on an all-fiber design.

2. Background

The optical path length variation is achieved by controlled heating/cooling of the fiber. The change in OPD in silica fiber can be expressed as [4]

$$\mathrm{OPD} = \left(\frac{\mathrm{d}n}{\mathrm{d}T} + \frac{n}{l}\frac{\mathrm{d}l}{\mathrm{d}T}\right) l\,\Delta T, \tag{1}$$

where l is the fiber length and n is the core index.

Typical values for the silica fiber are about [4]

$$\frac{\mathrm{d}n}{\mathrm{d}T} = -10^{-5}\,\mathrm{K}^{-1} \quad \text{and} \quad \frac{1}{l}\frac{\mathrm{d}l}{\mathrm{d}T} = 5 \times 10^{-7}\,\mathrm{K}^{-1}. \tag{2}$$

Therefore, the change of the refractive index with temperature represents the largest contribution to expression (1).

Relatively short sections of fiber attached to temperature-controlled surface can therefore induce significant OPDs.

3. Experimental design

The principal part of the scanning interferometer was a single-mode acrylate-coated optical fiber attached to the surface of a thermoelectric cooler.

In our experiment we used four low-cost Melcor Inc. (PT8-14-40) thermoelectric coolers positioned to form an $8 \times 8\,\mathrm{cm}^2$ temperature-controlled surface. The thermoelectric coolers were mounted on a water-cooled platform. Thirty-six meters of fiber was wound into a spiral monolayer and attached to the surface of the thermoelectric coolers with a thermo-conductive binding agent, supplied by Melcor Inc. (EG7655). The mechanical layout is shown in Fig. 1. The spiral was configured in Michelson interferometer where the appropriate fiber ends were chemically covered with a silver layer. The thermoelectric coolers were driven by a pulse-width-modulated (PWM) MOSFET H-bridge that enabled rapid sourcing and sinking of