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An inline sensing of coolant temperature inside a micro-channel for applications in ultra dense packed high power electronics

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ABSTRACT

An indirect cooling mechanism with coolants flowing through micro-channels absorbing the heat emanating from the ultra dense high power electronics chips and field programable gate arrays (FPGA) has been reported as the successful thermal management process in recent times. In such schemes, it is imperative to control the flow rate of the fluid so as to maintain the normal operating conditions/temperature on the area to be cooled. Such requirement necessitates the measurement of the temperature inside the micro-channels so as to sustain the needed circulation speed of the coolant. In the present paper, experimental measurement of the temperature of the fluids flowing through a closed loop micro-channel, by inserting an inline all-fiber micro Mach – Zehnder interferometer (MMZI) inside the channel, has been reported. During the study, three different fluids viz. water, isopropyle alcohol and copper nano particle mixed iso propyle alcohol, were circulated, at different flow rates, inside the 0.6 mm^2 channel. The variations in the characteristics of the light waves propagating through the fiber due to the presence of the fluid and its flow rate were observed on the optical spectrum analyzer. The temperature sensitivity of the MMZI for three fluids, in terms of shift in the output fringe pattern was determined as 0.372 nm/°C, 0.261 nm/°C. and 0.249 nm/°C, respectively.

1. Introduction

With the advent of ultra large scale integration (ULSI) technology, many-many thousands of electronic components can be packed within an area of ~1 cm^2. Under operating conditions, many of the densely packed electronic components/super computing devices emanate heat energy leading to formation of high thermal density regions within the chip/processor [1,2]. The operational behavior of the most of the futuristic ultra-thickly stuffed microelectronics and digital devices depends on the leakage/reverse saturation currents, which are heavily temperature dependent undesirable quantities whose larger value may lead to thermal breakdown of the any of the components on printed copper board [2]. Thus, even under normal operating conditions, due to the presence of large heat density, the circuit would perform as if over loaded. Under these circumstances, it is imperative to employ the cooling mechanism for continuous removal of undesirable heat from circuit components/processors so as to facilitate and maintain the smooth operation of the futuristic devices. Many nano-fluid coolants, flowing through the channels in contact with the electronic items, based indirect heat removal studies have been recognized and reported in the recent literature [3–5]. Whenever, more number of components of the circuits is operating, the higher heat has to be eliminated but the partial usage of the circuit requires lesser warmth to be taken off. In such practices, it is vital to determine the fluid flow rate for keeping the temperature within the prescribed limits specified for standard working state. Though the flow of coolants maintains the electronic circuitry in good health and improves its life, yet entail power consumption. The information related to temperature distribution within various parts of the electronic board is crucial and it determines the optimized coolant flow rate through circuit ensuring the minimum power consumption by the heat removal mechanical system. Thus, it is pertinent to know the real-time temperature of the fluid so as to optimize its flow rate for minimizing the energy consumption required for maintaining the necessary speed of the circulating fluid. The conventional temperature sensors lack stability, precision, and have drawbacks of slow response timing, prone to external disturbances and bulk size. These issues make the usual temperature sensors as obsolete and outdated for their usage in the next generation electronic circuit boards and the micrometer dimension sensors with fast response time could be ascertained as better choice. Optical fibers based temperature sensors could meet these stipulations due to their diameter ~micrometers, fast response time and time

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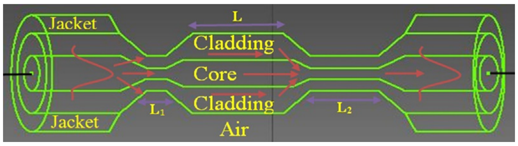

Fig. 1. Schematic configuration of an inline all-fiber MMZI.

tested technology. In the present paper, experimental evaluation of an all-fiber micro Mach – Zehnder interferometer (MMZI) as temperature sensor for electronic cooling applications has been reported. For conducting the experiment, a micro channel was formed on the copper plate with MMZI placed in it and different types of fluids were allowed to pass through micro channels containing MMZI. With change in the temperature of the fluid, the output spectrum of the MMZI fiber got altered and observed on the optical spectrum analyzer. The effect of flow rate and type of fluids on the spectral pattern emanating from the output port of the MMZI was recorded and presented herein. The experimental results confirm/establish the MMZI as fast, stable, accurate and miniaturized sensor with tremendous applications in electronic cooling/multi-channel evaporator/condensor, remote and harsh environment sensing applications.

2. Working principle

A MMZI is realized by concatenation of two bi-conical tapered fibers without any splicing [6–10]. The light passing through the first tapered region (length L_1) excites higher order cladding modes, which propagate through the un-tapered and unjacketed region (known as interference length/region with length L) with different propagation constants before again combining at the entrance of the second tapered fibers (length L_2) as shown through schematic in Fig. 1. The whole structure is similar to single-mode multimode and single-mode (SMS) design [11] without any splicing or mechanical arrangements for launching/capturing the light en-route from one section to the other. The down tapered section of the first fiber taper remains single mode, with only LP_{01} mode traversing through it, till its V parameter becomes ~0.84 [12]. Afterwards, the effect of core becomes negligible small and modes are predominantly guided through the cladding (as core) with air playing the role of cladding. Under these operating conditions, LP_{01}, LP_{02} and other higher order LP_{0m} modes get excited, nevertheless the most of the power initially contained in LP_{01} modes gets coupled with LP_{02} mode and power possessed by higher order modes is relatively small [8,10]. Since Jacket of the cladding had been removed, the cladding modes would also travel as guided modes through the distance between the two tapered sections (L) of the MMZI.

As these modes propagate with different propagation constants through the interference region, the accumulation of phase difference leads to the beating phenomenon among them. The superposed fields enter the second tapered section and undergo mutual coupling resulting into the formation of fringes at the output port. The free spectral range (FSR) of the interference pattern is decided by the length of the interference region. The most accepted relation, for the FSR ($\Delta\lambda$), by assuming the interference between LP_{01} and LP_{02} modes, is given below [6–8].

$$\Delta\lambda = \frac{\lambda^2}{\Delta n_{\text{eff}} L} \tag{1}$$

where, Δn_{eff} is the difference between the effective indices of the LP_{01} and LP_{02} modes.

It can be observed that the FSR/notch wavelength of the interferometer strongly depends on the length (L) of the interference region and difference between the effective indices of the LP_{01} and LP_{02} modes. The heat/temperature dependence of the fiber length and effective indices of the modes ensue the variations in the shift of the peak wavelength/fringes due to increase in temperature of the interference region. By using Eq. (1), the shift in the wavelength position with increase in temperature can be expressed as

$$\begin{aligned} \frac{\partial\lambda}{\partial T} &= \lambda\left(\frac{1}{\Delta n_{\text{eff}}}\frac{\partial\Delta n_{\text{eff}}}{\partial T} + \frac{1}{L}\frac{\partial L}{\partial T}\right) \\ &= \lambda\left(\frac{\alpha}{\Delta n_{\text{eff}}} + \frac{\beta}{L}\right) \end{aligned} \tag{2}$$

where, α and β are the thermo optic and thermal expansion coefficients of the fiber. The Eq. (2) has been derived from Eq. (1) with the assumption $\frac{1}{\Delta\lambda}\frac{\partial\Delta\lambda}{\partial T} = \frac{1}{\lambda}\frac{\partial\lambda}{\partial T}$. It may be noted that Eqs. (1–2) holds for the case when the interference between the only two modes (LP_{01} and LP_{02}) en-route the length L has been considered. The relation mentioned herein depicts the linear dependence of the wavelength with temperature and the shift of the wavelength, due to increase in the temperature, would be toward right hand side provided the thermal optic and thermal expansion coefficient are positive quantity. The construction of the experimental setup and the results are depicted in the next section of the manuscript.

3. Construction and experimental results

The one of the objective of the scheme is to measure the temperature of the fluid flowing through the 0.6 mm^2 channels by inserting the MMZI through it. The schematic arrangement of the experimental setup is shown in the Fig. 2. The experimental setup consists of gear pump coupled with ¼ HP three phase induction motor. The pump inlet takes the fluid from the 1500 ml capacity sump and passes it through micro channels and condenser before it enters the sump. A provision for varying the fluid flow rate and measuring its pressure en route from pump to channel has been kept by installing a flow control valve and a pressure gauge. The inlet and outlet of the channel block is fixed with T coupler to facilitate the passage of both fluid and MMZI fiber through the channel. The input end of the fiber was connected with the light source and output port was linked to the optical spectrum analyzer for observing the variations in the spectrum due to change in the temperature and flow rate of the coolants through the channel. The center plate of the channel block is fitted with the cartridge heater of 6 mm diameter and 45 mm depth which can deliver a maximum temperature of 200 °C. The construction details of the channels and fiber insertion is explained below.

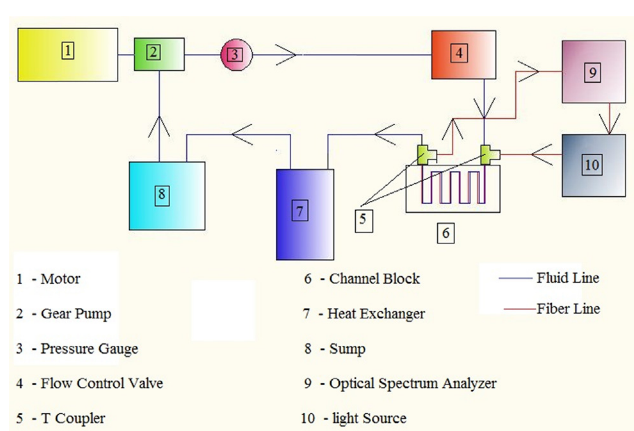

Fig. 2. Schematic Block Diagram for temperature sensing in mini channel with varying Trajectory.