Compact and Tunable Erbium-Doped Fiber Laser With Microfiber Mach–Zehnder Interferometer
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Abstract—A compact and tunable Erbium-doped fiber laser is demonstrated using a highly concentrated Erbium-doped fiber in conjunction with a microfiber Mach–Zehnder interferometer (MMZI) structure for the first time. A stable laser output is achieved at 1531.7 nm with a peak power of −19 dBm and an optical signal to noise ratio of 30.1 dB using a 980-nm pump at 100 mW power. The operating wavelength of the laser can be tuned from 1525.7 nm to 1527.7 nm by changing the path length difference (PLD) inside the MMZI from 1.6 to 2.7 mm at room temperature. It is also observed that the operating wavelength linearly shifts to a longer wavelength as the PLD increases with a tunable slope efficiency of 0.17 nm/mm. The tuning ability is due to the alteration of the induced optical phase shift inside the MMZI which affects the optical interference and the dominant peak which is responsible for the lasing action.

Index Terms—Erbium-doped fiber laser, microfiber Mach–Zehnder interferometer, tunable fiber laser.

I. INTRODUCTION

MICROFIBER based resonators have attracted considerable interest for a range of emerging applications in biomedical sensors [1], micro lasers [2], nonlinear optics [3], and optical signal processing [4], due to their small size and high quality factor. Compared to other types of micro-resonators [5]–[7], they offer simpler and/or more stable light coupling and can readily support single-mode operation. Mach–Zehnder interferometer (MZI) as a typical optical interference structure has consistently attracted considerable attention for applications in optical and photonic devices [8]. Recently, much research effort has been directed toward the development of microfiber-based Mach–Zehnder interferometer (MMZI) that can serve as optical filters, which have many applications in optical and photonic devices [9]. The MMZI can be assembled from a microfiber, which can be easily fabricated using the flame brushing technique.

Of late, there is also a growing interest on ultra-compact fiber lasers, which is attractive for both integration and operation in single longitudinal mode. They can be formed using a short length rare-earth doped fiber with high reflectivity dielectric mirrors deposited on the fiber facets to form a Fabry-Perot cavity [11]. Micro/nano scale lasers have also been demonstrated recently using semiconductor nano-wire [12] and laser dye [13] as the gain medium. In our earlier work, a compact erbium-doped fiber laser (EDFL) is demonstrated using a highly concentrated Erbium-doped fiber (EDF) as a gain medium in conjunction with microfiber knot resonator (MKR) at the end of the gain medium which functions both as a reflector and tunable filter [14]. In this paper, an MMZI based EDFL is demonstrated for the first time. The operating wavelength of the laser can be controlled by adjusting the path-length difference between the two arms of the MMZI laser.

II. EXPERIMENT

Fig. 1 shows the proposed MMZI-based EDFL, which consists of a piece of highly concentrated EDF with an MMZI at one end of the fiber and WDM coupler at the other end. A 980 nm laser diode was used as a pump to inject light into the EDF via the coupler. The gain medium was a 1.5 m long EDF with an Erbium ion concentration of about 2000 ppm of which a small section of the fiber end (about 3 cm long near one of its ends) was stripped and used for assembling the MMZI. The stripped portion of the EDF was horizontally held by two fiber holders where one of them was attached to a motorized translation stage that could be moved to taper the EDF using flame brushing technique. In the process, the position of an oxy-butane burner was controlled automatically so that it can be moved according to a specific algorithm to soften the uncoated EDF uniformly while the fiber was being stretched until the waist diameter was reduced to ~2 μm. It was crucial to distribute the heat from the burner evenly to avoid producing rough surface on the microfiber so that the transmission loss of the microfiber can be minimized. The fabricated microfiber has a length of 20 mm with a diameter of around 2 μm and a measured transmission loss of less than 0.06dB/mm.

This microfiber was cut and separated into two equal parts. By using tweezers, the left part was vertically bent while the right part was stretched straight horizontally and coupled to the left part. The left arm was then manipulated under a microscope using a pair of tweezers with the help of van der Waal and electrostatic forces to construct the MMZI. By careful micromanipulation, two evanescent couplers between two microfiber parts can be formed, resulting in the assembled microfiber MMZI. Fig. 2 shows the optical microscope image of the MMZI structure, which was captured when the red