sized ground-planes/laminates nor the connector. The gain was measured across the band and increased from 6.3 to 7.3 dBi. These results are consistent with the antenna presented in Ref. [2] and are slightly lower than the predicted gains of 6.8 to 8.7 dBi; however, the impact of the small ground-plane used and the associated increase in cross-polarization levels and backward directed radiation evident in Figure 3 can easily account for this discrepancy.

4. CONCLUSIONS

A technique that can potentially reduce the cost of an MMIC compatible printed antenna by reducing the amount of high dielectric constant material necessary to realize an efficient antenna has been presented. It was found that a thin layer of low cost, moderate dielectric constant laminate between the MMIC layer, and the first patch of a stacked configuration can still produce an efficient, broadband radiator.

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INFLUENCES OF PHOTODARKENING IN HIGHLY DOPING YTTERBIUM-DOPED FIBER ON PERFORMANCE OF FIBER LASER

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ABSTRACT: *The influences of photodarkening in highly doping ytterbium-doped fibers (YDFs) on the performance of fiber lasers were investigated in this study. The experimental results show that the threshold and the output power of the laser, respectively, increases and decreases over the pumping time, leading to the deterioration for the conversion efficiency of the laser. The deterioration is caused by the photodarkening of the YDF, which gives rise to additional loss for the YDF. This additional loss increases monotonically and irreversibly with the pump time. However, as the pumping time increases, the irreversible deteriorating process may be gradually fulfilled. The time needed for fulfilling this process depends on the length of the YDF and the pump used.* © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 1902–1904, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21774

Key words: *ytterbium-doped fiber; photodarkening; fiber laser*

1. INTRODUCTION

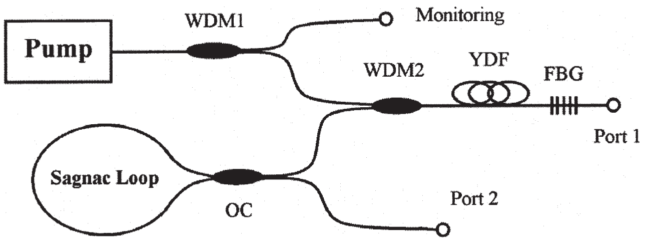

Figure 1 Schematic diagrams of experiments. WDM, wavelength-division-multiplexing coupler; YDF, ytterbium-doped fiber; FBG, fiber Bragg grating; OC, 3-dB optical coupler

Fiber lasers operating for single longitudinal-mode, high-speed ultrashort pulse, multi-wavelength or high-power have been achieved in the past [1–4]. However, the stability of fiber lasers is still a big issue for most practical applications. Various research results show that cavity lengths of fiber lasers are sensitive to the acoustical noise, leading to unstable operations for the fiber lasers. To suppress the influences of acoustical noise, an effective way is to use short-length cavity [5]. Thus, the doped fiber used may have to be shortened correspondingly. However, shortening cavity length may give rise to other problems such as the decrease of the output power. For this purpose, the doping concentration of the fibers may have to be increased. Unfortunately, some material effects, such as quenching, may limit the increase of doping concentration. Although doped fibers with high doping concentration have been developed for distributed feedback fiber lasers in recent years [6, 7], only the fibers doped with ytterbium ions, such as ytterbium-doped fibers (YDFs), and ytterbium and erbium co-doped fibers, may get very high doping concentrations because the simple level structure of ytterbium can avoid problems likes multiphoton decay, excited state absorption, and concentration quenching. However, lifetime quenching effects, leading to a strong unbleachable loss, was found in most YDFs, which may seriously affect the performance of the YDFs [8]. Meanwhile, photodarkening was reported for many rare-earth doped glasses, such as thulium, praseodymium, cerium, and europium [9], suggesting that the photodarkening may exist in silica-based doped fibers. In fact, infrared-induced photodarkening has been found in Tm-doped fluoride fibers [10], and also in highly doping YDFs most recently [11].

In this article, the influences of the photodarkening in highly doping YDF on the performance of the fiber lasers are investigated. Our experimental results show that the threshold and the output power of the laser, respectively, increases and decreases over the pumping time, leading to the deterioration for the power conversion efficiency of the YDF. This deterioration for power conversion efficiency of the YDF is a monotonic and irreversible process. However, as the pumping time increases to a few hours, the deteriorating process may gradually fade away.

2. EXPERIMENTS

Figure 1 shows the experimental setup. A linear cavity fiber laser was formed by a fiber Bragg grating (FBG) and a Sagnac fiber loop. The central wavelength and the reflectivity of the FBG are 1065 nm and 93.3%, respectively. The central operating wavelength of the nominal 3 dB fiber coupler used for the Sagnac fiber loop is 1060 nm. The active fiber being investigated is a commercial high doping concentration YDF, which have never been pumped or radiated. The YDF has a core diameter of 5 μm, cutoff wavelength of 775 nm, NA of 0.12, background loss of less than 40 dB/km, and absorption and emission at 974 nm of about 900 dB/m. The pump is a 975-nm laser diode with a FBG for stabi-

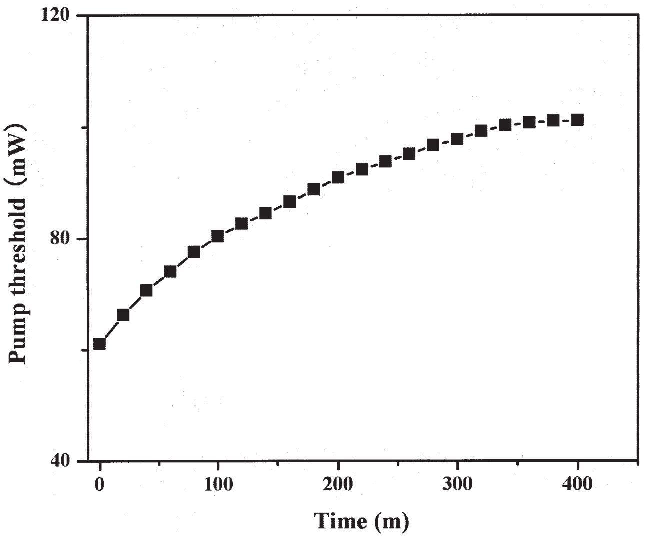

Figure 2 Threshold of the fiber laser as a function of the pumping time

lizing the frequency in the pigtail fiber, which has a maximum output power of 200 mW. Considering that the backward amplified spontaneous emission (ASE) near 975 of the YDF is generally very high, which may feedback to the pump through the 980/1060 nm WDM coupler and then affect the pump, two WDM couplers were used with the configuration as shown. The signal port of WDM1, therefore, may be used for monitoring the pump. Port 1 beyond FBG and port 2 from the 3-dB fiber coupler are used for the laser outputs.

3. RESULTS AND DISCUSSIONS

Initially, the threshold properties of the laser were investigated with a 25 cm YDF. The laser begins to oscillate when the pump is about 60 mW. However, with an optical spectrum analyzer (Agilent 86140B), we found that the laser stops lasing after several minutes. If then on increasing the pump, the laser restarts to oscillate and stops lasing again after several minutes, and it keeps repeating in this pattern. Figure 2 shows the measured threshold of the laser as a function of the pump time. As seen in the figure, the threshold increases over the pump time. In the beginning, the speed of increase of the threshold is faster but gradually becomes slow as the pump time increases. About 6 h later, the threshold becomes stable at 99.2 mW, which is more than its initial threshold (60 mW) by about 40 mW. It was also observed that, before the threshold reaches 99.2 mW, if the pump was turned off and then turned on again after a period of time, the threshold does not return to the initial one, but remains at the value when the pump was turned off, and then still shows the same increasing process stated earlier. In addition, this threshold property is not sensitive to the interval during which the pump is turned off. This phenomenon implies that the threshold increases beyond retrieve over the pump time; the increasing process is irreversible.

The output power of the laser under different fixed pumps was measured for different lengths of new pieces of YDF. Figure 3 shows the output power at Port 1 as a function of the pump time when the length of YDF and pump power are, respectively, (a) 25 cm and 120 mW, (b) 35 cm and 120 mW, and (c) 25 cm and 150 mW. One can see from the figure that the output powers for all the three cases decrease monotonically over the pump time. In all cases, the output power was rapidly decreased in the beginning, then becomes slow, and finally becomes stable after about 6–8 h. Such a power deterioration process in which the output power decreases over the pump time is in agreement with the increase of the threshold over the pump time. By comparing these three cases, we can see that for the same YDF length the time needed for fulfilling the power deterioration process is shorter when the pump is higher; under the same pump the time for this process is longer when the length of YDF is longer. Figure 3 also shows that in all the three cases the lasers are unstable and the output powers have large variations in the beginning, but the variation amplitude decreases over the pump time. After 6–8 h the amplitude of the variation is within 10 μW for case (a) and (c), but still as large as about 30 μW for case (b) because the length of YDF is longer. In the experiments, we also found that the relationship between output power and the pump time shown as Figure 3 is also an irreversible process.

It is worthy pointing out that monitoring results with a power meter at the signal port of WDM1 shows that the pump is stable during the whole experiments. In addition, with a ring cavity fiber laser scheme, the threshold and output power have the same relationships with the pump time, indicating that these effects are independent of the laser cavity.

The experimental results show that the conversion efficiencies decrease with the increase in the pump time. Because the pump is stable in our experiments, residual pump at Port 1 of the laser did not observed any obvious increases (considering the high absorption of the YDF, which may make it difficult to detect the residual pump at this port, we also used small length of YDF in our experiments, but the results are the same). Therefore, such power

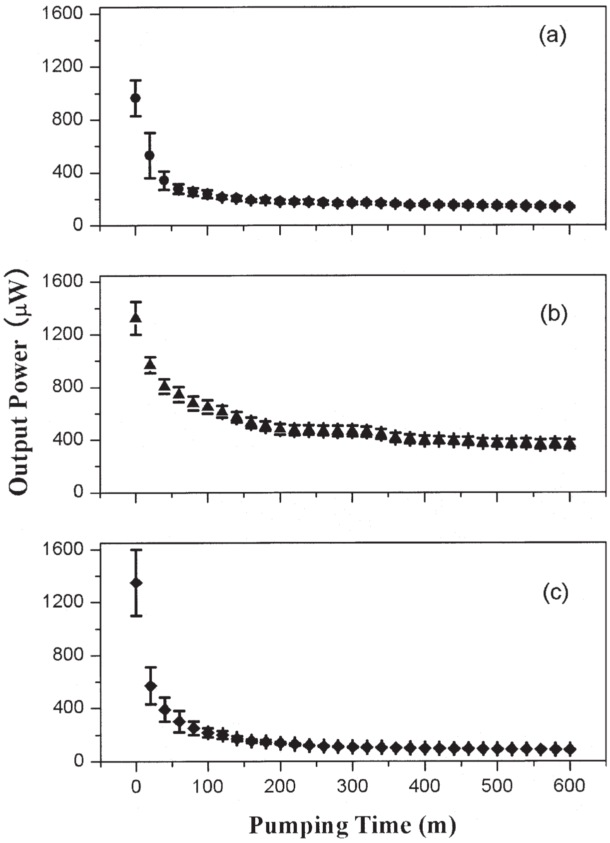

Figure 3 Output power of the fiber laser as a function of the pumping time when the length of the YDF and the pump are, respectively, (a) 25 cm and 120 mW, (b) 35 cm and 120 mW, and (c) 25 cm and 150 mW

conversion efficiency decreases with the pump time may not be caused by the decrease of the absorption of the YDF; it may result from some loss mechanism, which is a permanent loss from the irreversible process. On the other hand, in the experiments no residual pump changes (increases) were observed at Port 1, even when an axial tension was put on the YDF near its pump input end in the experiments, which eliminates the possibility that the pump may introduce any self-writing fiber grating effect on the YDF. Therefore, the power conversion efficiency decreases with the pump time for the laser should result from the photodarkening effect of the YDF, i.e., the action of pump radiation (including the lasing generated and the ASE) makes the YDF get a permanent and unrecoverable damage, which may be caused by the high-energy photons, or multi-photon absorption of the pump and the stimulated light emission [11]. In fact, all the experimental phenomena for the fiber laser can be explained by the photodarkening effect. The reason why the threshold gradually increases and the output power gradually decreases over the pump time may be because the non-absorbed loss of the YDF is increased by the photodarkening effect. As the pump time increases, the photodarkening effect gradually go to fulfillment, making the threshold and the output power of the laser to be stable finally.

4. CONCLUSIONS

We have investigated the influences of the photodarkening in highly doping YDF on the performance of the fiber lasers. Our experimental results show that the YDF, the threshold, and the output power of the laser, respectively, increases and decreases over the pumping time, leading to the deterioration for the power conversion efficiency. This is caused by the photodarkening of the YDF, which gives rise to additional loss of the YDF. This additional loss increases monotonically and irreversibly with the increase of the pump time finally to a stable value. Thus, the influence of such a photodarkening effect should be considered carefully when high doping YDFs are used for fiber lasers.

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INTERROGATION OF FIBER BRAGG GRATING SENSOR BASED ON Er-DOPED FIBER LASER

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ABSTRACT: *A novel interrogation of fiber Bragg grating (FBG) in a strain sensor, which is based on Er-doped fiber laser’s transient regime, is reported. The applied strain on FBG changes the laser cavity loss, which in turn modifies the laser’s transient regime. The strain value can be obtained by measuring the build-up time of the laser. This method translates wavelength shift information into time domain that can be accurately measured with low-cost electronic devices. In the experiment, the strain sensitivity can be adjusted by simply controlling the pumping level of the laser, a sensitivity of 1.66 με/μs is achieved under fitful pumping level.* © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 1904–1907, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21773

Key words: *fiber Bragg grating (FBG); strain sensor; fiber laser; transient regime; time domain*

1. INTRODUCTION

In recent years, fiber Bragg grating (FBG) sensors have shown great potential in a variety of applications [1], such as smart structure and environmental monitoring. Some of the principal reasons are small size, low weight, and immunity to electromagnetic interference. Furthermore, FBG sensors offer the potential for multiplexing and remote sensing [2]. The basic principle of FBG sensors is that, under the influence of the parameters to be measured such as strain and temperature, the Bragg wavelength of FBG changes [1]. Therefore, in order to obtain the information of the measurand, we need to design practical interrogation for detecting the wavelength shift of FBG. Various interrogation schemes have been developed [3–9]. Some examples include the configurations based on Fabry–Perot filters [3], wavelength division multiplexer [4], Mach–Zehnder interferometers [5], matched gratings [6], fiber lasers [7, 8], and Sagnac loop using chirped gratings [9]. In general, the wavelength shift information is obtained from the amplitude or phase value of electrical output. To our knowledge, the technique that translates the measurement of wavelength shift into time-domain is uncommon [10]. Recently, we have proposed a novel interrogation for FBG in a strain sensor using time-domain measurement based on Er-doped fiber (EDF) laser’s transient regime. The laser cavity is composed of two wavelength-matched FBGs and one of the gratings also acts as the sensing element.

In our work, the sensing FBG is placed in the laser cavity, and the laser pump is modulated by a low-frequency square signal. The