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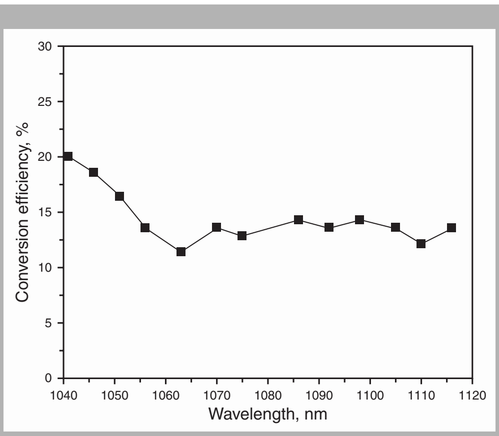
Abstract: We report wide wavelength tuning in a double-clad ytterbium-doped fiber laser. The laser cavity consists of an array of broadband high-reflection fiber Bragg gratings and a bulk grating as output coupler and wavelength selection element. The proposed fiber laser configuration combines low intra-cavity loss of fiber Bragg grating mirrors with wide wavelength tuning of bulk gratings. We demonstrate > 70 nm wavelength tuning range, limited only by the available fiber Bragg gratings.



Fiber laser spectral efficiency

Wide wavelength-tuning of a double-clad Yb^{3+}-doped fiber laser based on a fiber Bragg grating array

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1. Introduction

Double-clad Yb^{3+}-doped fiber (DCYDF) lasers are recognized as an attractive medium to obtain high brightness, high power and broad wavelength tuning capability [1,2]. In particular, Ytterbium-doped fiber lasers have been thoroughly investigated due to their simple energy level configuration [3,4]. And also, due to their capability of delivering high powers with diffraction-limited output beams [5]. In these fiber lasers, wavelength tuning can be obtained using external bulk elements such as diffraction gratings and mirrors, or using all-fiber components such as fiber Bragg gratings (FBG's). In addition, Yb^{3+}-doped fiber lasers can be used as pump sources for Raman generation [6] and they have even been considered as a suitable medium for laser tuning in novel ceramic nanocrystalline materials, although with very limited results in terms of the tuning range obtained [7,8]. Furthermore, non-linear gain in a co-doping scheme to obtain multi-wavelength lasing has recently been proposed [9]. In the first case of Yb^{3+} wavelength tuning in fibers, the cavity mirrors consist of a diffraction grating and a broadband mirror, which can be an external mirror or the 4% Fresnel diffraction from a perpendicular cleaved end [1].

The main drawback in this case is the difficulty to align and couple the laser light from the bulk optics elements

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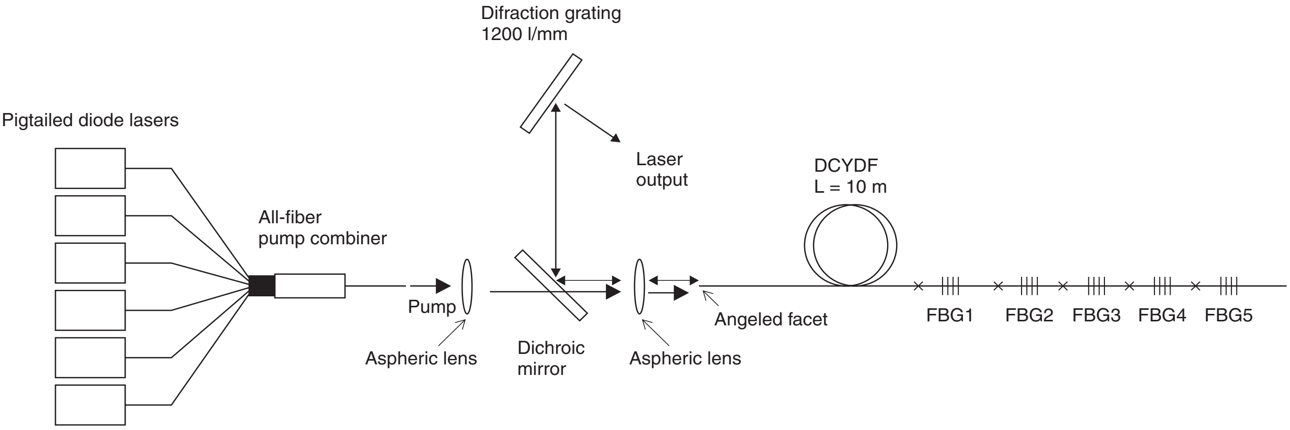

Figure 1 Experimental setup

into the active fiber core, and the low reflectivity on both ends which results in a laser with two output ports. In the second case the insertion losses are rather low due to the fact that the FBG is directly spliced to the active core of the DCYDF and the tuning is realized by applying compressive stress on the FBG to shift the Bragg wavelength to a desired point [10]. In general, the output coupler reflector is formed by the 4% Fresnel reflection of the perpendicular cleaved end. Since in this case the continuous wavelength tuning of the laser wavelength requires the change in the stress state of the FBG, there may be some issues about reliability, particularly when the fiber is operated at high powers [11]. Both methods of wavelength tuning have advantages and drawbacks. Another option is to combine the wavelength selection capability of bulk diffraction gratings and the low insertion loss of FBG's.

On the other hand, there have been advances in both Q-switch and continuous wave regimes when Yb^{3+}:YAG has been used. Yb^{3+}:YAG has properties such as long upper level life time, low emission cross section high quantum efficiency, and no concentration quenching, although careful temperature control is required [12,13].

Moreover, one of the advantages of Yb^{3+} in silica fiber lasers compared to solid state micro-chip lasers, is that re-absorption is not strongly affected by temperature due to the inherent heat-dissipation properties of the fiber structure; while set-ups based on the aforementioned lasers generally require a precise control of its operating temperatures [14,15].

In this work, we propose a fiber laser device where the laser cavity consists of an array of broadband high-reflection FBG's and a bulk diffraction grating, which serves as wavelength selective feedback element and output coupler. Using the proposed hybrid set-up, we demonstrate a wide continuous wavelength tuning range of ~ 73 nm, and conversion efficiency in the order of 15% with respect to the absorbed pump power. The tuning range is limited by the available FBG's and the gain profile of the DCYDF.

2. Experimental setup

Fig. 1 shows a schematic diagram of the setup used for the widely tunable double-clad Yb^{3+}-doped fiber laser. The pump setup consisted of four pigtailed laser diodes operating at 915 nm that were combined through a pump combiner [16]. The output fiber from the pump coupler was a 0.45 NA multi-mode (MM) fiber with a core of 125 μm diameter, coated with a low index polymer. The output from the pump coupler was collimated by an aspheric lens and then coupled into the DCYDF by another aspheric 4-mm focal length lens. The DCYDF was ~ 10 m long, with core/cladding dimensions of 6/125 μm, and 0.14/0.45 of numerical aperture. Between the two aspheric anti-reflection coated lenses was a dichroic mirror to protect the pump direct laser light onto the 1200 lines/mm diffraction bulk grating. The grating was set up in a Littrow configuration an acted as a wavelength selective feedback element and as output coupler in the zero-order. To suppress Fresnel reflection from the end of the DCYDF at the pump side, the end was angle cleaved, which reduced launched pump power by 10%. The other end of the DCYDF was directly spliced to an array of five broadband high-reflection FBG's, covering a wavelength range from 1040 to 1120 nm. The center wavelength, reflectivity and FWHM values of the reflectivity of the FGBs are as follows: 1046.94 nm, 90.7% and 14.72 nm, 1064.91 nm, 100% and 8.64 nm, 1068.72 nm, 91.64% and 10.4 nm, 1086.19 nm, 99.7% and 9.88 nm, 1116.24 nm, 99.12% and 10.05 nm, respectively. By varying the angle of the grating we were able to produce feedback and tune the laser wavelength from 1043 nm to 1116 nm, as shown in Fig. 2. Output power and wavelength tuning were measured from the bulk grating end of the set-up via power meter and a conventional optical spectrum analyzer.

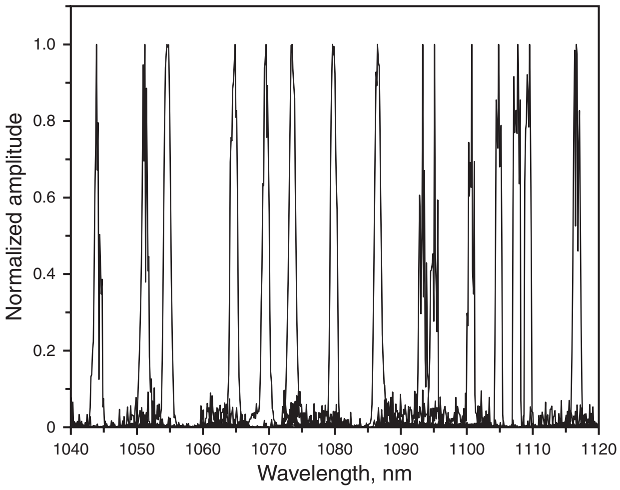

Figure 2 Fiber laser tuning range

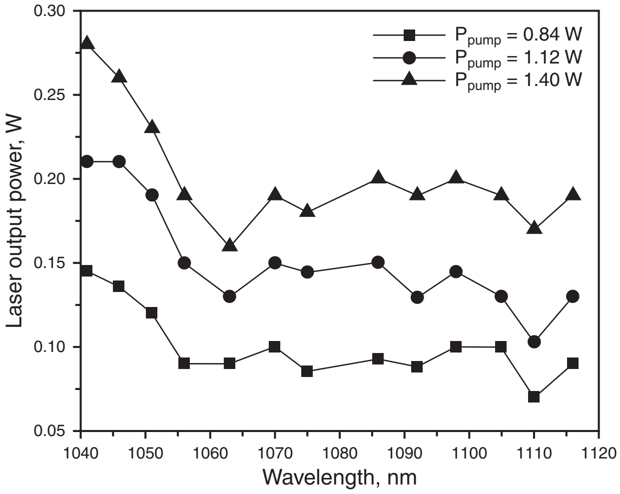

Figure 3 Fiber laser spectral output power

3. Results and discussion

Fig. 2 shows the normalized output spectra of the laser lines generated by the tunable DCYDF laser. As mentioned above, the cavity was formed with the FBGs array and a bulk 1200 lines/mm grating arranged in the set-up in Littrow configuration. As can be observed, the tuning range is in the order of ~ 73 nm. It is possible to tune the laser to longer wavelengths, however, since the composed reflection spectrum of the FBG array does not cover that range, a considerable portion of the generated laser light leaks out through the side of FBG array. Since our main interest is in the output laser light from the diffraction grating, we did not perform any measurements at wavelength regions out of the reflection band of the FBG array.

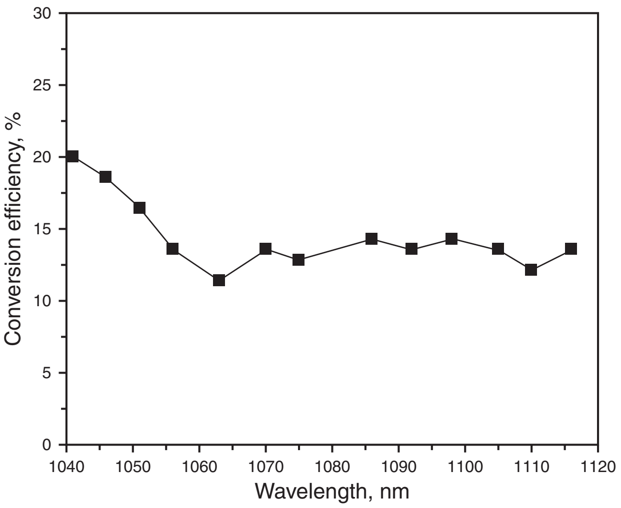

Figure 4 Fiber laser spectral efficiency

Logically, improvements in the FBG array would bring a broader tuning range, with relatively low losses.

Fig. 3 shows a graph of the output laser power at different wavelengths, as a function of the absorbed pump power. On this curve, a constant linewidth of approximately 1.5 nm can be observed over the entire tuning range. Fig. 4 shows a graph of the conversion efficiency as a function of the wavelength. The conversion efficiency of the laser is around 15–20%, over the full tuning range. The main reason for this relatively low laser efficiency is high reflectivity found at both ends of the cavity, which can be improved by using a bulk grating with fewer lines per millimeter. The lasers output spectra remained partially stable in the transition between gratings as a few wavelengths were continuously competing for the preferential gain of the Yb^{3+}-doped core. This effect would disappear with the use of a wider range, chirped FBG's, where each one covers a specific wavelength range, so that the effect of a given set of FBG's can be eliminated by introducing loss at specific points [17], or by using tunable stop-band fiber filters [18,19]. This is subject of our current efforts to improve the laser performance and we believe that the use of these techniques will allow us to extend the tuning range over 100 nm.

4. Conclusion

This work describes the demonstration of a hybrid, widely tunable (of over 70 nm tuning range) fiber laser. The range of tuning was only limited by the availability of FBGs and the insertion losses were relatively low. The simple 10 m Yb^{3+}-doped fiber was capable of emitting from 1043 nm up to 1116 nm with the use of a set of FBGs and a 1200 lines/mm bulk grating, which formed the cavity. Improvement in the tuning range depends only on the availability of FGBs at longer than 1120 nm wavelengths.

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