行政院國家科學委員會補助專題研究計畫成果報告

應用不同反射率之光纖光柵作功率等化多波道光源及增益等化摻鉺光纖放大器的分析與研究

Study and design of power-equalized WDM laser sources and gain-flattened EDFA based on fiber gratings of various reflectivities

計畫類別：■個別型計畫　□整合型計畫
計畫編號：NSC89－2215－E－009－019
執行期間：88 年 08 月 01 日至 89 年 07 月 31 日

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中華民國 89 年 10 月 17 日

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一、中文摘要

光纖雷射在特性上，已被證實具有極窄線寬(Linewidth)與很小波長/溫度飄移係數(Δλ/°C)，非常適合作為數位與類比傳輸光源，針對分波多工且功率等化雷射光源之設計，我們提出並聯泵激分光式結構，對於波道間功率等化之問題，使用參數調整法，包含使用多個光可調衰減器、控制泵激雷射分光比率、增益介質長度與光纖光柵反射率等方式，來製作功率等化分波多工(WDM)雷射光源模組，此模組可包含多個並聯在一起之分佈式布拉格反射型(Distributed Bragg Reflector)光纖雷射陣列，以摻鉺光纖為增益介質可藉由單一980nm 或 1480nm 之半導體雷射泵激，藉由適當之參數調整法，頻道間之平均輸出功率差值可由 7.2 dB 降至降到 0.1 dB 以下。此模組具有體積小及價格低廉之優點，於分波多工傳輸系統中，於雷射光源提供了更多樣化的選擇，使光纖傳輸系統得到更佳的傳輸品質。

關鍵詞：分波多工、雷射陣列、功率等化、光纖光柵

Abstract

By using fiber gratings as pump reflectors with various reflectivities or N pieces of gain fibers with various lengths externally to linear cavity as self-equalizers, a parallel-type, pump-shared, linear cavity laser array (LCLA) is proposed and numerically studied. The average output power is increased and the maximum power variation among channels is reduced from 7.2 to less than 0.1 dB when the reflectivity of each pump reflector or the length of each gain fiber is adjusted appropriately.

Keywords: wavelength division multiplexing, laser arrays, power equalization, fiber Bragg grating

二、緣由與目的

Fiber lasers have been extensively investigated for vast applications in multichannel optical lightwave communications, fiber optic sensors, optical signal processing and wavelength conversion, etc. In order to increase the information capacity using wavelength division multiplexing (WDM) transmission, the realization of stable, narrow linewidth and equal output power lasers with multi-wavelength operation in the 1.55 μm band has attracted lots of attention and been extensively developed recently. With the feature of wavelength insensitivity to temperature at least an order of magnitude better than that of semiconductor lasers, erbium-doped fiber laser (EDFL) is a promising candidate for multi-channel lightwave communications. Several previous techniques have been proposed for multiwavelength operations. These techniques are based on several short-period fiber Bragg gratings (FBGs), a semiconductor optical amplifier array, splicing five distributed feedback lasers together and pumping with a 1480-nm semiconductor laser and using two comb filters in the ring-cavity.

In this work, we propose a power-equalized linear cavity laser array

(LCLA) based on parallel pump-shared configuration. The simulation is based on the spectral model of optical amplifier. A pump-diode is parallel pump-shared to N-channel fiber laser array with the merit of avoiding mutual injection effect among channels. Each fiber laser unit consists of a piece of erbium-doped fiber (EDF) and fiber grating-pair with identical wavelength. Because the non-flatten gain spectrum of EDF in the 1.55 μm band, power levels among channels are wavelength dependent and unequal even when all the parameters such as pumping power values, lengths of EDF and the reflectivities of grating-pair are identical. Several pump reflector gratings or gain fibers are added for individual channels to increase the pump absorption ratio and equalize the lasing signals. Theoretical analysis and calculated results of the power-equalized LCLA on varying the reflectivities of pump reflectors are addressed in sections II and III, respectively. Before and after power-equalization, the maximum power variations among channels, ranging from 1530- to 1560 nm, are 7.2 and 0.1 dB, respectively.

三、結果與討論

To obtain single-frequency operation, the laser cavity length should be short. Fig. 2 (a)-(b) report the residual pump power as a function of different wavelengths for the LCLA before and after the pump reflectors are added. When these pump reflectors are added, the backward pumping is introduced (i.e., round-trip pumping). The average increment of pumping power absorption is 85% when compared to the condition without using pump reflectors. In the latter case, the average pumping absorption is 31%. The reason for low pump absorption may be due to the short cavity length or low Er^{3+} concentration. To further increase the pumping absorption ratio, high concentration $Er^{3+}:Yb^{3+}$ codoped fibers could be applied as they are quite well-developed. On the other hand, the residual backward pump light not absorbed in the laser cavities may travel back to the pump diode if no 980 nm fiber isolator is used in Fig. 1. Fig. 3 (a)-(b) shows the superposed output spectra of the eleven-channel LCLA. Before the 980-nm grating reflectors are used, the average output power is -5.8 dBm and the maximum power variation among channel is 7.2 dB, as shown schematically in Fig. 3 (a). After these 980 nm pump reflectors with 100% reflectivity are used, the average output power is increased to 1.8 dBm and the maximum power variation is decreased to 1.6 dB, as indicated in Fig. 3 (b). Fig. 3 (c) shows that power variation is further reduced to 0.1 dB when the 980 nm pump reflector gratings with appropriately reflectivities, ranging from ~100% for the weakest channel (ch. 6) and 55% for the strongest channel (ch. 11), are placed at the output ends of the fiber lasers. The result confirms the feasibility of using pump reflector gratings as power equalizers.

Another technology based on the concept of master oscillator power amplifier (MOPA) may also increase the power levels of these WDM sources. It is based on adding another section of gain fiber, rather than a pump reflector grating as shown in Fig. 1, at the output end of each fiber laser. The gain fiber is then pumped by the residual pump energy not absorbed in the laser cavity. The residual pump powers and output signals are different among channels. N pieces of gain fibers with various lengths are placed at the output ends of the fiber laser array for power equalization and further amplification. One important issue is that the residual pump power must be strong enough to provide adequate inversion of the ions within the small lengths of EDF segments. According to the calculated results, the required lengths of EDFs are ranging from 0 cm for channel 11 to 57 cm for channel 6. Fig. 4 shows the required EDF length against channel wavelength of the fiber laser array. The WDM sources are power equalized by varying the lengths of gain fibers. Fig. 5 shows that the average power level is –2.9 dBm and the maximum power variation among channels is less than 0.1 dB.

Considering the serial-type, pump-shared (STPS) scheme LCLA, which is based on writing the gratings (e.g. fiber laser unit) in separate pieces of gain fiber. Such configuration has the benefit of higher pump absorption than that of the PTPS scheme LCLA. On the other hand, the pump power needs to provide enough population inversion in the N cascaded pieces of EDF, the STPS scheme LCLA may require low absorption gain fibers to ensure a reasonably identical pumping of the individual lasers. The issues to power-equalized these WDM channels sources is currently under study.

四、結論

In summary, we have proposed and numerically studied two technologies for power-equalizing the N-channel LCLA with PTPS scheme. Either of them is based on adding pump reflectors or N pieces of gain fibers as self-equalizers. Beside the enhancement of pump power absorption, power variation among channels is reduced from 7.2- to 0.1 dB when the pump reflectors with appropriate reflectivities, or the EDFs with appropriate lengths are added into the LCLA. The power-equalized LCLA, with graceful features of easily power level adjustment and no mutual injection effect, may find highly attraction for a wide variety of communications and fiber sensor applications.

專利申請

1. S.-K. Liaw, H.-Y. Tseng and <u>S. Ch</u>"功率等化多波道光纖雷射陣列"

論文發表

1. H.-Y. Tseng, S.-K. Liaw and <u>S. Chi</u>, "Power-equalized parallel-type pump shared fiber lasers based on parameter-adjustment," *Optics Communications*, vol. 170, pp. 229-234, 1999.
2. S.-K. Liaw, H.-Y. Tseng and <u>S. Chi</u>, "Parallel pump-shared linear-cavity fiber lasers arrays using 980 nm pump reflectors as self-equalizers," *IEEE Photon. Technol. Lett.*, vol. 12, pp. 19-21, 2000.
3. S.-K. Liaw, H.-Y. Tseng and <u>S. Chi</u>, "Power-equalized parallel-type pump-shared fiber lasers using strain-tunable fiber Bragg gratings, "to be published in *Optics and Lasers in Engineering*.
4. H.-Y. Tseng, S.-K. Liaw and <u>S. Chi</u>, "Parallel pump-shared linear-cavity fiber lasers arrays using 980 nm pump reflectors," presented in *Photon Taiwan' 99. Chung-Li, Taiwan.*

五、計畫成果自評

研究內容與原計畫相符程度應在90%以上，本計劃之相關論文已投稿國際期刊3篇，以及國內會議論文1篇並獲接受，國際會議論文2篇待近一步消息，估計達預定目標90%左右，本計劃同時以理論及實驗分析最佳參數情況，其重要性分別如敘述於下:

學術上：證實功率等化雷射光源之設計上可行性，並且以理論及實驗分析，我們也比較國外串聯式雷射陣列之限制及其優缺點，也建立一套光纖雷射之運算機制，可為爾後此議題之研究參考，成果並且發表於知名國際期刊上。

實務上：由於價格、溫度穩定度等條件之優越性，我們已申請一專利，此建議模組若商品化，可以應用在高密度分波多工系統中，由於 DWDM 技術方興未艾，本計劃除訓練相關之工業人才外，灌輸其觀念與設計能力外，研究成果亦可應用於光纖通信網路中。

六、參考文獻

1. S.-K. Liaw et al., *Optics Communications*, vol. 156, pp. 255-259, 1998.
2. C. E. Zah et al., *Electron. Lett.,* vol, 28, pp. 824-826, 1992.
3. A. Hamakawa et al., *in OFC'97*, pp. 297-298, Dallas, TX, USA, paper ThM3, 1997.
4. P. Varming et al., *in OFC'97*, pp. 31-32, paper TuH4.
5. J. Chow et al., *IEEE Ptoton. Technol. Lett.*, vol. 8, pp. 60-62, 1996.
6. C. R. Giles, E. Desurvire, *IEEE J. Lightwave Technol.* LT-9, pp. 271-283, 1991.
7. A. Cucinotta et al., *Optics Communications*, vol. 156, pp. 264-270, 1998.
8. W. H. Loh et al., *J. Lightwave. Technol.* vol. 16, pp. 114-118, 1996.

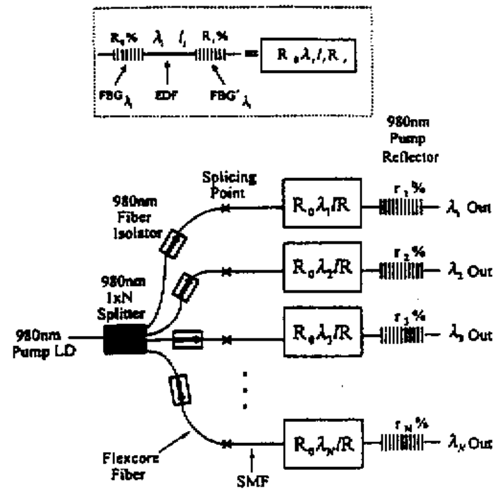
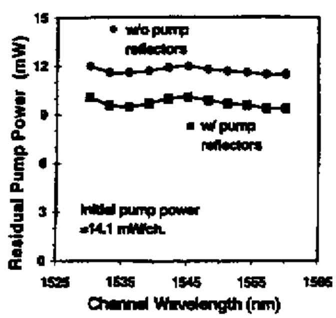


Fig. 1. Proposed configuration of the parallel-type, pump-shared scheme linear cavity laser arrays using grating-based pump reflectors as power-equalizers. Inset shows the ith linear cavity laser unit with $1 \leq i \leq N$.



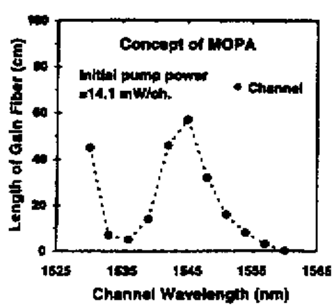


Fig. 2. Residual pump power at the output end of the linear cavity laser. For each cavity, the pump power is about 14.1 mW and the length of EDF is 15 cm. The reflectivities of FBG pair at both ends are 100% and 75%, respectively.

Fig. 4. EDF lengths against channel wavelength of the fiber laser array. The WDM sources are power equalized by varying the lengths of gain fiber.

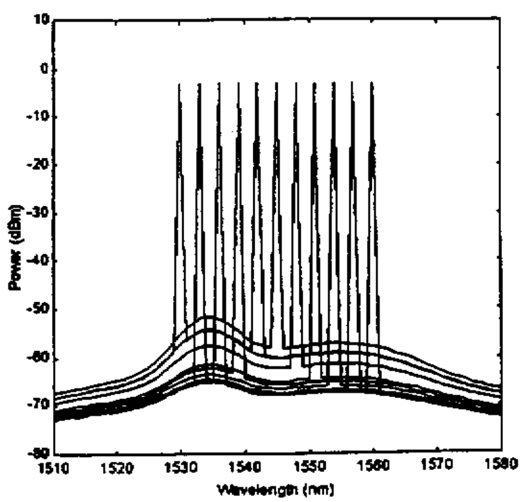


Fig. 5 Superposed output spectra of the eleven-channel linear cavity laser array. Power variation is less than 0.1 dB after the length of EDF in each channel is properly adjusted.

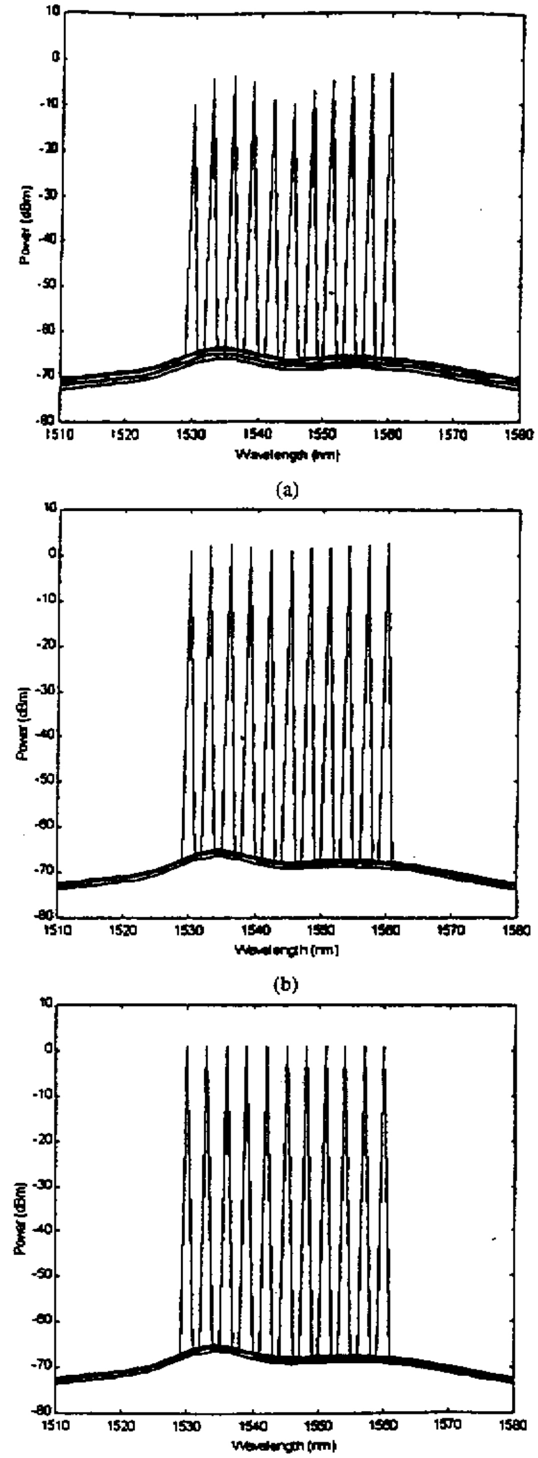


Fig. 3. Superposed output spectra of the eleven-channel linear cavity laser arrays. Power variations are: (a) 7.2 dB, (b) 1.6 dB before and after the 980-nm pump reflectors with 100% reflectivity are added, and (c) power variation is further reduced to 0.1 dB when the reflectivities of pump reflectors are properly adjusted.