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Design and fabrication of Bragg grating based DFB fiber lasers operating above 1610nm

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The erbium doped distributed feedback (DFB) fiber laser with an UV induced phase-shift was introduced in 1995 [1]. It provides a stable, single-mode laser for applications in optical communication [2,3]. It combines a high signal to noise ratio, robust single-mode operation and narrow line-width (~1kHz).

Optical amplifiers and sources in the L-band (1570nm – 1610nm) have recently attracted a lot of attention for optical networks. L-band components increase the capacity and flexibility of WDM systems by increasing the available bandwidth. Further, L-band components enable WDM transmission on installed dispersion shifted fibers, since at the high wavelengths there is sufficient dispersion to suppress four-wave mixing generated channel crosstalk [4]. The development of erbium doped fiber amplifiers for the L-band suggests the erbium doped DFB fiber laser as a promising candidate to provide a high quality source covering the wavelength range from 1530-1615nm.

We use a numerical model [5] to optimize the DFB laser design for L-band and report experimental results obtained with DFB fiber lasers at 1608nm and 1613nm. We find that the intrinsic fiber loss is an important parameter, which limits the obtainable laser output power and determine the optimum value of the Bragg grating strength for a fixed length. UV induced loss, which depends on the wavelength and the intensity of the UV beam as well as the fiber design and dopants normally dominate the intrinsic loss. Finally we investigate the temperature dependence of a laser.

The numerical model is based on the steady state rate equations for Er^{3+}-ions in combination with coupled mode equations between the forward and the backward propagating DFB-laser modes. The model includes a fast varying spatial hole burning caused by the fast varying interference pattern between the forward and backward laser modes and a slowly varying hole burning caused by the spatial variation of the laser field intensity. The intrinsic fiber loss is included, but the model does not include exited state absorption (ESA) between the $^4I_{13/2}$ and $^4I_{9/2}$ (800nm pump band) energy levels. The ESA is negligible around 1550nm but becomes significant around 1610nm.

In the following we consider fiber gratings pumped with 60mW at 980nm. We use the room temperature emission and absorption cross sections and the erbium concentration ($\rho=1.18\cdot10^{25}m^{-3}$) from the fiber used for the 1608nm DFB fiber lasers presented later in the paper. A discrete phase-shift of π is positioned at the center of the grating, allowing the laser to operate at the Bragg wavelength, λ_B.

Figure 1 (a) and (b) shows the DFB laser output power as a function of the intrinsic loss parameter, α, calculated for λ_B =1608nm, different values of the gratings coupling coefficient, κ (proportional to the index modulation), and for Bragg grating lengths, L, of 50 and 100mm. The figure shows that in the lossless case the output power increases with κL, but as κ increases the laser becomes very sensitive to the intrinsic fiber loss, and consequently there exist an optimum value $\kappa L \leq 10$ that will result in the highest output power for a realistic value of the loss [6]. When κL increases, the Q-value of the cavity also increases. Therefore the cavity lifetime of a photon increases and when the cavity lifetime becomes comparable to the absorption lifetime α/c a significant fraction of the photons will be lost by intrinsic absorption. Further numerical calculations show that the maximum obtainable output power increases linearly
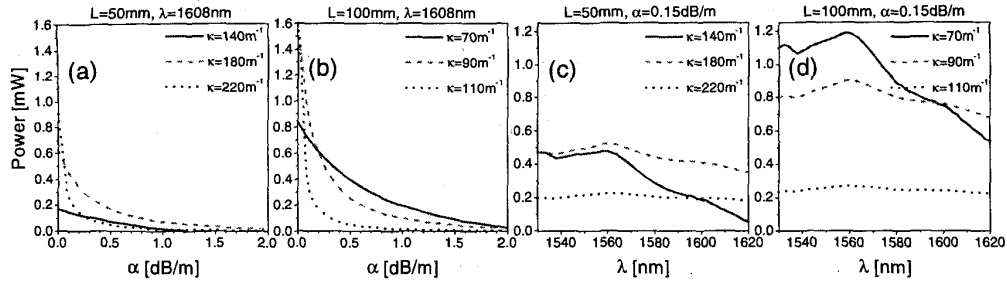
Fig. 1: DFB laser output power at 1608nm as a function of the intrinsic loss parameter, calculated for different values of the coupling coefficient, κ, and for Bragg grating lengths of (a) L=50mm and (b) L=100mm. Calculated laser output power as a function of the lasing wavelength. (c) L=50mm. (d) L=100mm.

with the grating length, and for a fixed value of the intrinsic loss the maxima are found for a constant value of κL [5]. This means that the optimum value of the coupling coefficient is $\kappa_{opt}=K/L$, where the constant K depends on the intrinsic fiber loss, the erbium concentration and the power confinement factor.

In figure 1 (c) and (d) the fiber laser output power is shown as a function of the lasing wavelength for Bragg grating lengths, L, of 50 and 100mm, assuming an intrinsic loss of 0.15dB/m. The result suggest that lasing is possible above 1600nm, but the output power at the highest wavelengths may be overestimated due to the influence of ESA. The shape of the curves depends mainly on the κL product, although the influence of the intrinsic loss increases, as the grating becomes longer. For a 50mm long grating a very high coupling coefficient ($\kappa{\sim}180m^{-1}$) provides the highest output power around 1600nm. In contrast, a rather low coupling coefficient ($\kappa{\sim}90m^{-1}$) provides the highest output power around 1600nm when a 100mm long Bragg grating is used.

Encouraged by the numerical results we conducted experiments using two different erbium doped fibers. The first fiber was the erbium doped fiber described in the model above, whereas the second fiber has much higher gain with peak absorption of 62dB/m at 1530nm. Lasing of 100mm long lasers above 1600nm was obtained for both fibers and figure 2 shows the corresponding lasing spectra. For the first fiber the best lasing was obtained for κ=90m^{-1}, while an unstable lasing was obtained for κ=100m^{-1}. The difficulty of optimizing the lasers phase-shift was severely increased by the UV induced loss. Stable single-polarization and single-mode lasing was observed after annealing the laser at 200°C, which decreases the UV induced intrinsic loss. The output power of 25μW (60mW of 980nm pump) is around 16dB less than we can obtain around 1550nm. The pump threshold is 16mW. In the second fiber we could easily obtain lasing with κ=85m^{-1} and 95m^{-1}. Single-mode operation was achieved after inducing the phase-shift. After annealing, the output power was 0.62 mW (60 mW of 980nm pump). The pump
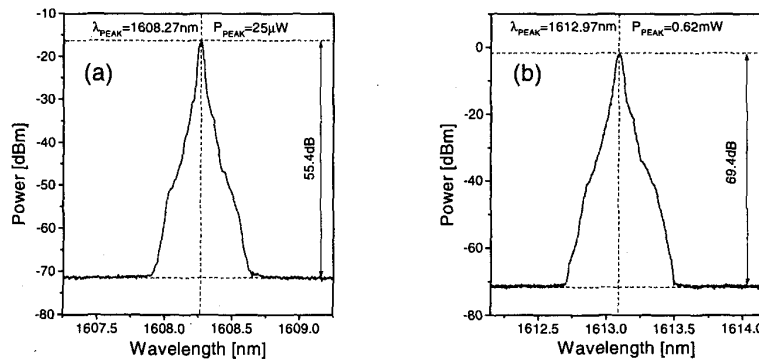

Fig. 2: Lasing spectrum of DFB fiber lasers. (a) κ=90m^{-1}, L=100mm, 60mW of 980nm pump, fiber 1. (b) κ=95m^{-1}, L=100mm, 60mW of 980nm pump, fiber 2
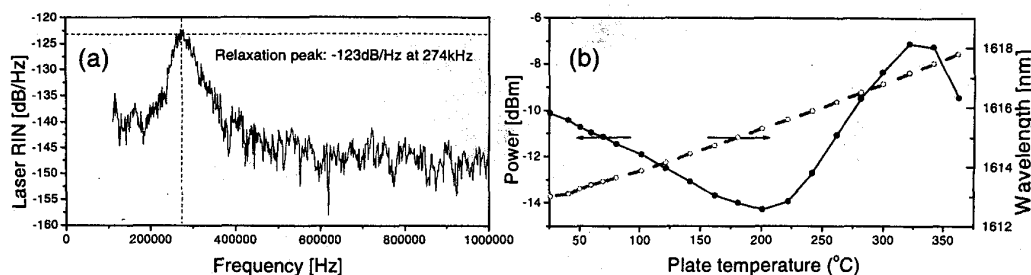
Fig. 3: (a) Laser RIN spectrum, (b) Temperature tuning characteristics

threshold is around 3 mW. The difference between the lasers with $\kappa=85m^{-1}$ and $95m^{-1}$ is very small, and the sensitivity to the magnitude of the induced phase-shift and the laser packaging made it impossible to distinguish which is better.

Figure 3a show the noise spectrum of the laser. The relative intensity noise (RIN) of the laser is −123 dB/Hz at the relaxation peak (273kHz) and above 1MHz the laser RIN is below the measurement limit of the HP Lightwave Analyzer.

The laser operation at high temperature was investigated by placing it on a heating plate. The temperature was kept constant for 10 minutes at each step, measuring a set of laser wavelength and corresponding output power. The result is shown in figure 3b. We observe a linear wavelength shift with temperature and reach 1618nm at 360°C. The output power shows a complicated behavior with temperature. Below 200°C we believe this is due to various changes in the gain spectrum. Above 320°C the power decreases as the grating is becoming significantly weaker and thermo-mechanical loss from the fiber coating and packaging increases.

In conclusion we have shown that it is possible to manufacture DFB fiber lasers with wavelengths at least up to 1618nm. Numerical simulations show that it is possible to increase the output power by using a longer Bragg grating for the laser cavity. However, for long lasers, the output power depends strongly on the intrinsic fiber loss, which makes a moderate coupling coefficient of the Bragg grating the optimum choice for long lasers. We have presented two fiber lasers using different erbium doped fibers. The lasers operate at 1608nm and 1613nm respectively and both provide stable single-mode and single-polarization lasing as needed for sources used in L-band communication.

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