Protecting a Power-Laser Diode from Retroreflections by Means of a Fiber $\lambda/4$ Retarder

V. Annovazzi-Lodi, *Member, IEEE*, S. Donati, *Member, IEEE*, S. Merlo, L. Zucchelli, and F. Martinez

Abstract—**A quarter-wave retarder made by a small loop of fiber on the laser pigtail is an effective means to protect the laser from retroreflections. Suppression factors of about 20 dB have been achieved with negligible insertion losses. An example of application is given. A method to measure the isolation is also presented.**

POWER laser-diodes for pumping rare-earth doped fiber amplifiers need a careful control of backreflection into the laser cavity because of the unusually low reflectivity (1% or less) of the output facet that is found to optimize the output power. In addition to disturbing effects like intensity noise, spectrum broadening and emission peak shift [1]–[4], retroreflection can cause the catastrophic failure of the laser because of excessive power density inside the cavity.

The first source of backreflection is the pigtail end in front of the laser output facet, which must be antireflection coated (down to <0.5%) or properly angled (or both) to make its effect negligible. In addition, reflections arise at the splices down the fiber, e.g., at the joint between the pigtail and the pump WDM and at the WDM/active-fiber joint. On the other side, with a pigtailed laser alone, there is a relatively strong Fresnel reflection (4%) at the fiber end.

Obviously, one can use an optical isolator to suppress both reflection and scattering contributions sent back into the cavity. However, at $\lambda = 980$ nm standard YIG garnets are not transparent, and thus other expensive crystals must be used. All-fiber Faraday isolators can also be considered [5], but they are usually bulky and rather expensive.

By noting that the dominant contribution in a short fiber is reflection rather than scattering, use can be made of the reproducible relation between the polarization states of onward and backward waves. Assuming that the laser output is linearly polarized, a good suppression of the backward wave can be achieved by the well known combination of a linear polarizer and a 45° quarter wave retarder, as shown in Fig. 1(a).

We have studied this approach because it is a simple and inexpensive alternative to a standard Faraday isolator. Also, it can be used in combination with a single stage nonreciprocal isolator to implement a lower cost double-stage device.

For an all-fiber implementation, the $\lambda/4$ retarder can be made as a small loop [6] wound directly on the fiber pigtail of the laser diode [Fig. 1(b)]. The phase retardation $\Delta\phi$ of one loop is proportional to $1/R$ [6] and the radius R_q for a quarter wave retarder is about 1–2 cm in ordinary fibers, so that the bend loss for the fundamental mode is very low (<0.2 dB). Also, the retarder-axes orientation can be adjusted by rotating it around the fiber.

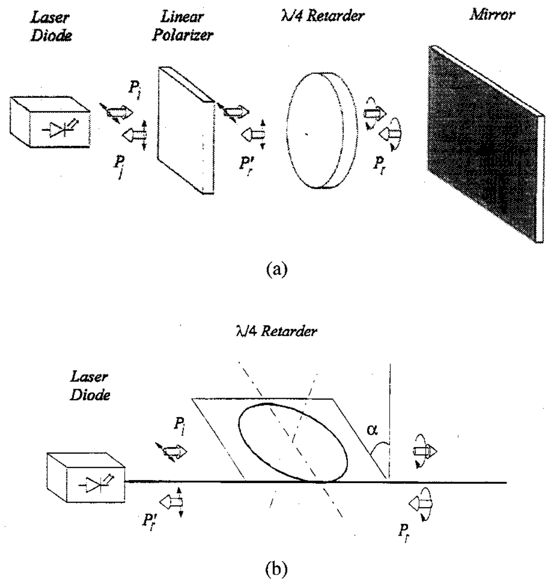

Fig. 1. (a) Backreflection isolator made by a polarizer and a $\lambda/4$ retarder. (b) Proposed all-fiber implementation on the laser pigtail with the laser itself acting as a polarization sensitive element.

As a fiber polarizer one can use a coil of HB or ZING fiber [8], introducing, however, another splice before the retarder. The alternative solution we present in this letter relies on the polarization selectivity of the laser diode itself, which is much less sensitive to backreflections that are polarized orthogonally to its emission. This property can be simply modeled by a built-in linear polarizer in front of the laser, with unitary transmission for the axis parallel to the laser emission and an extinction factor $\eta > 1$ for the orthogonal polarization. Let us now consider the isolation, defined as the power ratio P_r/P_j in Fig. 1(a). In our scheme [Fig. 1(b)], isolation cannot be measured directly, since one can only detect the reflected power P_r' toward the laser, while the power P_j coupled into the laser mode should be evaluated indirectly as $P_j = P_r'/\eta$. In addition, though we can measure the degree of polarization η' of the laser emission, we cannot assume $\eta = \eta'$ without experimental verification.

Manuscript received October 30, 1995; revised December 13, 1995. This work was supported by MURST 40%.

The authors are with the Dipartimento di Elettronica, Universitá di Pavia, Via Ferrata 1, I-27100 Pavia, Italy.

Publisher Item Identifier S 1041-1135(96)02615-8.

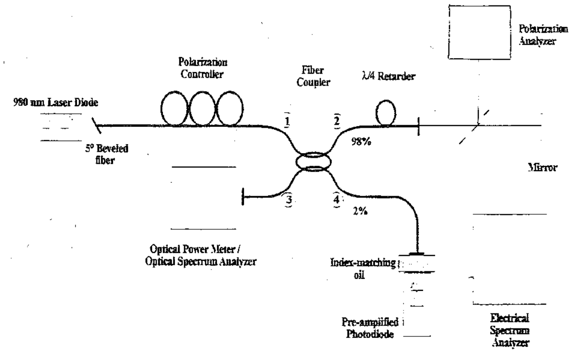

Fig. 2. Experimental setup for the measurement of isolation by injection modulation.

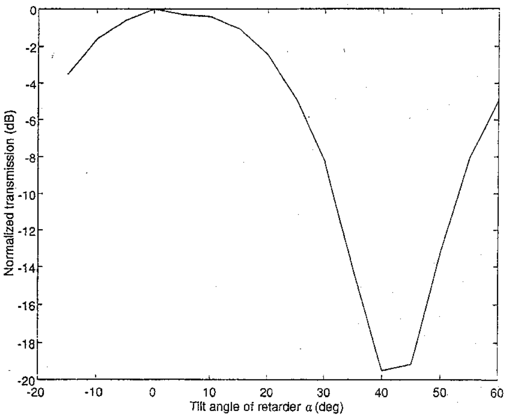

Fig. 3. Power transmission of the laser/retarder as a function of the angular position α of the retarder (after correction from the calibration curve). An isolation of about 19 dB is found as the difference between $\alpha = 0$ and $\alpha = 45^\circ$. The sharpness of the notch at 45° is limited by the noise of the spectrum analyzer.

In order to quantify the effect of retroreflections, we have devised an injection modulation scheme. Specifically, we apply a weak-level retroreflection by means of a mirror, and analyze the amplitude modulation of the laser output which is induced by a small amplitude sweep on the laser current. The setup is reported in Fig. 2. The laser is coupled to a 5° beveled fiber (port 1), so as to minimize backreflections from that interface; a 98–2% pump coupler allows us to send back to the source a fraction of the emitted power reflected by a mirror (port 2). The backreflected power can be adjusted by tilting the mirror and is measured on port 3, where the laser spectrum can also be monitored; on port 4 the laser power is detected by a photodiode and its fluctuations at electrical frequencies are measured by a FFT spectrum analyzer.

In the experiment, we used a polarization controller to get a linearly polarized state from port 2 feeding the λ/4 retarder. In a practical device implementation, the controller is unnecessary, since the λ/4 is wound close to the laser.

It has been shown [2], [7] that under weak feedback conditions ($C \ll 1$), the laser output power is changed by a quantity:

$$\Delta P = \Delta P_{\max} \cos \omega \tau, \tag{1}$$

where $\Delta P_{\max}$ is proportional to the injected electric field, ω is the laser frequency and τ is the round-trip delay from the laser to the mirror.

If we now frequency-modulate the laser, by linearly increasing the pump current at a constant rate $d\omega/dt$, we can write for the optical path:

$$\omega\tau = (\omega_0 + \Delta\omega)\tau = \omega_0\tau + (d\omega/dt)t\tau, \tag{2}$$

where $d\omega/dt = (d\omega/d\lambda)(d\lambda/dI)(dI/dt)$.

The output power is thus amplitude modulated by a quantity $\Delta P_{\max}$ at a frequency:

$$\omega_m = (d\omega/dt)\tau = \frac{4\pi L}{\lambda^2}\,\frac{d\lambda}{dI}\,\frac{dI}{dt}, \tag{3}$$

where L is the distance between the laser and the mirror. The factor $d\lambda/dI$ depends on the source and is of the order of 1–10 pm/mA, while dI/dt is the slope of the ramp superposed on the bias current. On the spectrum of the photodetected current, $\Delta P_{\max}$ is the amplitude of the peak at frequency ω_m. For typical values of parameters, e.g., $L = 2$ m, $dI/dt = 0.2$ A/s, $d\lambda/dI = 2$ pm/mA, it follows that $f_m = \omega_m/2\pi \cong 2$ kHz. The current spectrum also contains the harmonics of the sawtooth wave modulating the output power; however, these components can be prevented from overlapping ω_m by an appropriate choice of the sawtooth frequency. The reflection from the fiber end in front of the mirror would result in a peak at a different frequency, since it arises from a different distance. However, we preferred to splice an antireflection coated fiber to port 2 of the coupler for a more reliable readout. The reflection from the splice does not affect the measurement since it is small and represents just a constant contribution (not affected by the retarder). The reflection on port 3 is highly attenuated (4×10^{-4}) by the coupler.

Since (1) is valid for single mode and single polarization regime, $\Delta P_{\max}$ depends only on the component E_j of the reflected field parallel to the laser cavity mode, and thus correctly include the laser sensitivity to polarization. However, $\Delta P_{\max}$ is proportional to the injected electric field E_j only for very low feedback [2], [3], [7], and therefore calibration of the setup is necessary. This is simply done by removing the retarder (or orienting its axes along the laser output polarization) and drawing the diagram of $\Delta P_{\max}$ as a function of P_r' (or P_3), which can be varied by adjusting the mirror.

Later, the isolation of the arrangement is obtained by measuring $\Delta P_{\max}$ as a function of the $\lambda/4$ orientation α [Fig. 1(b)] at constant reflected power. At $\alpha = 45^\circ$, one finds the maximum attenuation of $\Delta P_{\max}$, which gives the isolation after correction by the calibration curve. Experiments were carried out on a SDL 6570 pump laser, mounted on chip carrier, which performed monomode operation at $\lambda = 975$ nm. The fiber was a sample of Photonetics UDOS-103, i.e., the pigtail of the coupler; the quarter wave retarder was obtained with a single loop of 19 mm diameter.

The relative position between the laser and the beveled fiber tip was carefully adjusted, and then cemented, to get a stable spectrum. The working distance was about 300 μm.

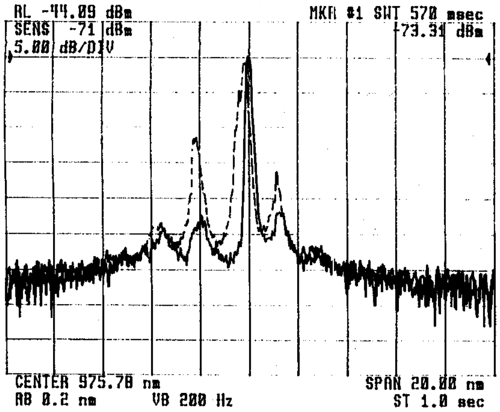

Fig. 4. Spectra of the pump laser with feedback (dotted line) when the retarder is ineffective ($\alpha = 0$) and when it is properly oriented at 45° (full line).

In the experiments, we used the parameter values reported above as an example; the value $d\lambda/dI = 2$ pm/mA has been obtained after measuring ω_m for different slopes of the sawtooth waveform.

First, we got the calibration curve $\Delta P_{\max}$ versus P_3 (Fig. 2); a roughly linear diagram was obtained in log/log scale, with a significative deviation from the 10 dB/dec slope one would expect [2], [7] if $\Delta P_{\max}$ is assumed proportional to the injected field. The mean slope was 17 dB/dec, with evidence of reduced coherence regime [3].

Later, we measured the extinction of the retarder/laser system. The transmission diagram is reported in Fig. 3 as a function of the angular position α of the quarter wave loop. A minimum was found at $\alpha = 45°$, as expected, and the corresponding power attenuation represents the isolation.

After optimizing the retarder radius, typical measured values were around 20 dB. This result is in agreement with the figure we would obtain from our basic model of the laser, by assuming $\eta = \eta'$. The insertion loss of the retarder was negligible (<0.1 dB). Small changes ($\approx 1°$) in the angular position of the retarder, due for example to ambient vibrations would not significantly reduce isolation (see Fig. 3). Although until now we have assumed a linearly polarized source, we have tested our approach on lasers with a small (<4°) degree of ellipticity. We have found, both by numerical analysis and experimentally, that in this case the isolation is only slightly reduced, provided that one properly adjusts the retarder angular position. For a higher degree of ellipticity, the retarder must be tuned by slightly modifying its radius.

The effectiveness of the approach is evident from Fig. 4, where the spectrum of the pump laser is reported, at a reflected power level of 0.1% with respect to the source output power, for two extreme situations: with the retarder ineffective (oriented at $\alpha = 0$) where spectral distortions are evident (dotted line), and with a fully effective retarder at $\alpha = 45°$, where the spectrum is again that of the unperturbed laser (full line).

REFERENCES

[1] C. R. Giles, T. Erdogan, and V. Mizrahi, “Reflection-induced changes in the optical spectra of 980-nm QW lasers,” *IEEE Photon. Technol. Lett.*, vol. 6, no. 8, pp. 903–906, Aug. 1994.

[2] R. Lang and K. Kobayashi, “External optical feedback effects on semiconductor injection laser properties,” *IEEE J. Quantum Electron.*, vol. QE-16, no. 3, pp. 347–355, Mar. 1980.

[3] K. Peterman, “External optical feedback phenomena in semiconductor lasers,” *IEEE J. Select. Topics Quantum Electron.*, vol. 1, no. 2, pp. 480–490, June 1995.

[4] G. R. Jacobovitz-Veselka, P. Wysocki, A. M. Vengsarkar, T. Erdogan, V. Mizrahi, and J. Borick, “Single-stage booster amplifier with two 980 pumps stabilized by fiber grating,” in *Proc. Optical Amplifiers and their Applicat.*, Davos, 1995, pp. 162–165.

[5] V. Annovazzi-Lodi, S. Donati, S. Merlo, and A. Leona, “All-fiber Faraday rotator made by a multiturn figure-of-eight coil with matched birefringence,” *J. Lightwave Technol.*, vol. 13, pp. 2349–2353, Dec. 1995.

[6] R. Ulrich, S. C. Rashleigh, and W. Eichoff, “Bending induced birefringence in single mode fibers,” *Opt. Lett.*, vol. 5, pp. 273–275, June 1980.

[7] S. Donati, G. Giuliani, and S. Merlo, “Laser diode feedback interferometer for measurement of displacement without ambiguity,” *IEEE J. Quantum Electron.*, vol. 31, no. 1, pp. 113–119, Jan. 1995.

[8] S. Donati, L. Faustini, and G. Martini, “High-extinction coiled-fiber polarizers by careful control of interface reinjection,” *IEEE Photon. Technol. Lett.*, vol. 7, pp. 1174–1176, Oct. 1995.