Leakage Current Measurement in Multielectrode Lasers Using Optical Low-Coherence Reflectometry

Uwe Wiedmann and Philippe Gallion

Abstract—**In multielectrode lasers, the interelectrode spacing is often reduced in order to avoid the saturable absorber effect in this region, which could cause instabilities of the laser. This leads to an interelectrode leakage current between adjacent electrodes. Measuring this leakage current by conventional means is very difficult and often inaccurate, in particular, when the part of the leakage current reinjected into an active region has to be determined. Based on optical low-coherence reflectometry, a method is presented which allows the measurement of this leakage current with an error smaller than 10%. Additionally, the effective group indexes of the laser waveguide and its bulk material will be determined.**

Index Terms—**Leakage current, multielectrode lasers, OLCR.**

I. Introduction

OPTICAL low-coherence reflectometry (OLCR) is a measuring technique used for localizing and quantifying reflecting discontinuities and irregularities in optical waveguides. The basics of this technique were developed ten years ago [1], and to date many different applications have been investigated [2]–[4]. However, only few investigations into active components have been reported [5]. This is somewhat astonishing, as OLCR not only is nondestructive, but also gives the opportunity to analyze active optical components under operating conditions. Comparisons of reflectometric signatures of a single element for different operating points can give valuable information about the processes going on in the component under test. As an example, the measurement of the interelectrode leakage current in a two-electrode laser is presented.

In its basic form, an OLCR setup consists of a broadband light source and a scanning Michelson interferometer with the device under test placed in one of its arms. By varying the optical path length of the other arm, a spatially resolved reflectogram is obtained. The setup [6] used for the measurements presented here is shown in detail in Fig. 1. The spontaneous emission of an erbium-doped fiber amplifier has been used as the low-coherence source. This avoids the appearance of artifact signatures caused by a ripple in the source spectrum, a problem often encountered when the light source is a superluminescent diode.

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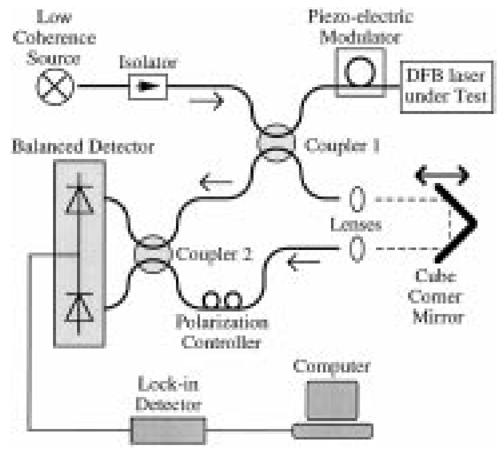

Fig. 1. The OLCR system.

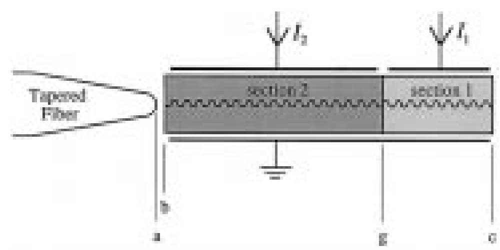

Fig. 2. The DFB laser under test.

II. Measurement of the Leakage Current

The leakage current is measured most easily by making comparative measurements. The presentation of two such measurements would suffice to illustrate the procedure and determine the leakage current, but two more measurements will be shown to prove the validity of this proceeding.

The laser tested here is shown in Fig. 2. It is a distributed-feedback (DBF) laser with relatively low coupling coefficient $\kappa \approx 10$ cm^{-1} and uniform grating, but with the upper electrode split up into two sections. The Bragg wavelength of the grating is 1560 nm. The length of the first section (on the right) is 400 μm, and the second section is 800 μm long. A tapered fiber is used for coupling between the fiber and the laser.

The first measurement, presented in Fig. 3, shows the relative backreflection level as a function of mirror position in air, with no current injected into the laser under test. Point a on the horizontal axis corresponds to the end reflection of the tapered fiber, point b to the front end reflection of the laser, and c_1 to the back end reflection of the laser. Under the given conditions, the active region of the laser is strongly absorbing,

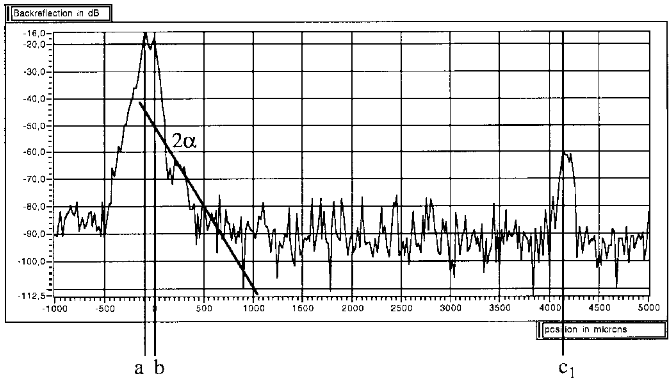

Fig. 3. Reflectogram obtained when the DFB laser is not biased.

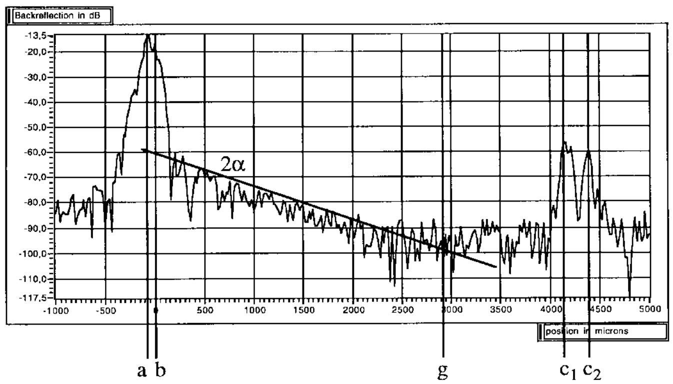

Fig. 4. Reflectogram obtained when current is injected into first electrode only.

which is confirmed by the measured absorption coefficient $\alpha \approx 140\ \text{cm}^{-1}$. With such a high absorption, the end reflection of the laser would not be visible. Peak c_1 is thus due to light not propagating in the active region of the laser, but rather in the substrate. From the measured optical distance between the front and back end reflection of the laser and its measured physical length, the refractive group index of the laser material is determined to be $n_g \approx 3.4$.

A second measurement, shown in Fig. 4, has been carried out with a current of $I_1 = 60$ mA injected into the first section (situated between g and c) and no current I_2 injected into the second one (between b and g). It can be seen that now the absorption coefficient has decreased to $\alpha \approx 31\ \text{cm}^{-1}$. It must be stressed that this value has been determined for the second section, into which no current at all has been injected. The difference between the two absorption coefficients measured must thus be due to a leakage current from the first electrode into the active region of the second section. The constant slope of the backreflection suggests homogeneous current injection into the second section. This can be done by a leakage current from the first to the second electrode near the surface of the semiconductor device. As all the electrodes are highly conducting, this current then spreads out on this electrode to be reinjected homogeneously into the second section, as illustrated in Fig. 5. This interelectrode leakage current will obviously depend on the biasing conditions, and be equal to zero when both upper electrodes are connected to the same potential.

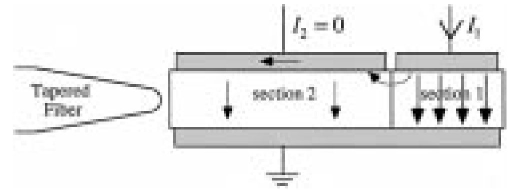

Fig. 5. Current flow in the unequally biased DFB laser.

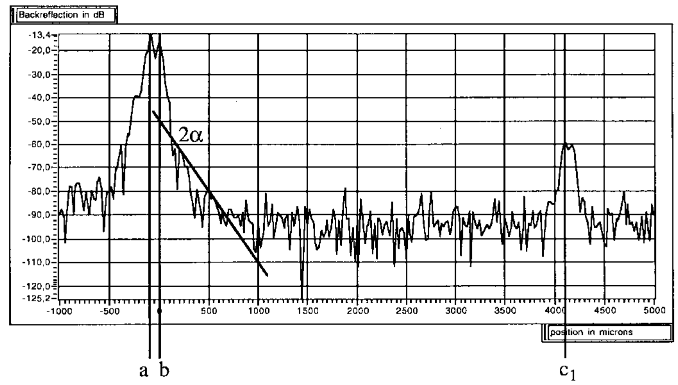

Fig. 6. Reflectogram obtained when current is injected into first electrode, and second electrode is grounded.

In Fig. 4, we also note the appearance of a second end reflection peak c_2. This peak is now due to the portion of the injected light actually propagating in the active region and thus in the laser waveguide. The effective group index for this light path is $n_{g,\text{eff}} \approx 3.6$, which is slightly higher than the one for the light propagating in the substrate. It is in good agreement with its value as determined from the Fabry–Perot resonances at threshold.

To test the hypothesis of the current path including the second electrode, a third measurement has been carried out with the same injection current to the first electrode and with the second electrode grounded. The short-circuit current from the second electrode to ground was measured to be 10 mA. The reflectogram obtained is shown in Fig. 6. It is essentially the same as in the case without any injection current. This means that the current injected into the second section is now very close to zero. This confirms our assumption that no current is injected directly from the first electrode into the second section, but that the current path always also includes the second electrode. The value of the leakage current can now be determined by a measurement where the current is injected directly into the second section. To eliminate any possible interelectrode leakage currents, the first and the second electrode will be connected (see Fig. 7). As the laser under test is homogeneous over all its length, the fraction of the total current injected into the second electrode and thereby into the second section is approximately proportional to the length of this electrode. Fig. 8 shows the result of a measurement where the total current injected equaled $I_1 + I_2 = 6.5$ mA. The current injected into the second section was thus $I_2 \approx 4.3$ mA. The reflectogram obtained shows an absorption coefficient of $\alpha \approx 31\ \text{cm}^{-1}$, which is the same value as in Fig. 4, where a current of $I_1 = 60$ mA was injected into the first electrode only. This comparison shows that for an injection current of

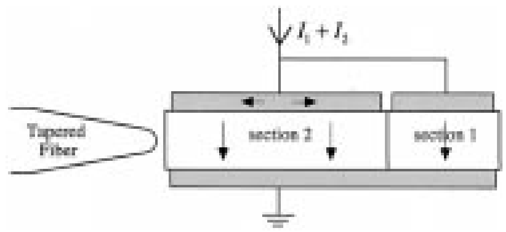

Fig. 7. Current flow in the homogeneously biased DFB laser.

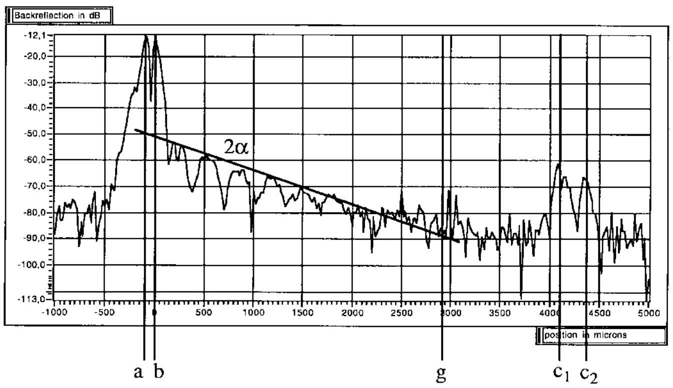

Fig. 8. Reflectogram obtained when current is injected homogeneously into both electrodes.

$I_1 = 60$ mA into the first electrode and no injection current into the second electrode, the interelectrode leakage current equaled 4.3 mA. It must be stressed that this result is very different from the leakage current measured with the second electrode grounded, which had been 10 mA. This shows that a simple measurement of the short-circuit current by far overestimates the value of the leakage current under normal operating conditions. This has to be compared to the accuracy of the leakage current measurement using our method, which was better than 10% for the operating point investigated. This accuracy is limited by the precision of the slope estimation of the jagged distribution, and the slope variation with injection current; this variation is very strong for the last measurement.

The measurements also showed that the leakage current was not at all proportional to the injection current into the first section, but rather rose nearly proportional to the injection current when this latter was small, and saturated quite quickly once it exceeded 10–15 mA. This is due to the fact that for higher currents the threshold voltage of the p-n-junction of the laser diode is reached, which stabilizes the voltage from the first electrode to ground. With the resistance between the two upper electrodes being practically independent from the applied voltage, the leakage current between these two electrodes also stabilizes. This shows that the laser diode can appropriately be modeled electrically by two diodes to ground with their hot ends being connected by a constant resistance. We have, thus, demonstrated that in the investigated laser carrier diffusion effects from one section to the other close to or in the active region can be neglected compared to the interelectrode leakage current close to the surface of the device, even in the extreme case where bias current is injected into one section only. Once this has been confirmed, the interelectrode leakage current in other biasing conditions can be calculated from the electrical model.

A comparison of the reflectograms shown in Figs. 4 and 8 shows that they even agree for the first section, although the biasing conditions have been very different for this section. This is mainly due to the fact that the noise level of the measurement is already reached before point g, so that different absorption coefficients after this point do not show up in the reflectogram.

III. Conclusion

We have demonstrated that the measurement of the interelectrode leakage current in multielectrode lasers is possible with an error smaller than 10% using optical low-coherence reflectometry. This result has been obtained by comparing the reflectograms measured for different operating points of the laser under test. We have also shown the appearance of two different end reflection peaks of the laser under test, which can be attributed to a portion of the injected light propagating in the laser waveguide and another one propagating in the substrate.

Acknowledgment

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