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**Short Temporal Coherence
Optical Source With External
Fiber Optics Cavity**

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Short temporal coherence optical source with external fiber optics cavity

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Resumo

A técnica de colapso da coerência temporal é abordada teórica e experimentalmente para o desenvolvimento de fontes ópticas de espectro largo ($\Delta\lambda \approx 10$ nm). Para produzir realimentação óptica externa, a cavidade expandida é implementada através da diminuição da refletância da faceta de saída do laser semiconductor e da adição de um trecho de fibra óptica monomodo, terminada com um espelho refletor. Estas fontes ópticas de banda larga encontram aplicação no desenvolvimento de giroscópios a fibra óptica de médio e alto desempenho, por terem espectro largo, baixo ruído, alta confiabilidade, baixo custo e serem compactas.

Abstract

The temporal coherence collapse technique is theoretical and experimentally treated to the development of broadband optical sources ($\Delta\lambda \approx 10$ nm). In order to produce external optical feedback, an expanded cavity is introduced by reducing the laser output facet reflectivity and adding a monomode fiber optics stretch with a mirror deposited in its edge. These broadband optical sources are used in medium and high-performance fiber-optic gyroscope development due to their large spectrum, low noise level, high reliability, low cost and compactness.

1. INTRODUCTION

The fiber-optic gyroscope (FOG) [1] is a successful product to date in the field of interferometric fiber-optics sensors. Currently, high-performance FOGs can detect accurately very small rotation rates, which induce phase shifts in the submicroradians range via the Sagnac effect [2]. The accuracy obtained is mainly due to the use of broadband sources ($\Delta\lambda \approx 10$ a 30 nm FWHM). In opposition to the needs of the telecommunications market, which depends on very narrow band lasers for long-distance transmissions, FOGs need to be operated with sources exhibiting an emission spectrum as broad as possible. The goal is to promote the decorrelation among spurious field components traveling on different paths in the optical circuit which otherwise would interfere coherently at the interferometer output, adding undesirable noise and drift to the output signal [3].

Usually, FOG's sources are superluminescent laser diodes (SLD) or optical fiber lasers (OFL), such as those using a piece of Er-doped fiber as the laser cavity. Both are usually expensive sources. The coupling of enough SLD emitted light into the optical fiber circuit is difficult due to its inherent broadband emission. A few hundreds of microwatts pigtailed to a single-mode fiber is a typical figure for a SLD. The OFL light is generated along the doped fiber, making the coupling to an external fiber circuit easier. However, OFL sources are rather expensive due to the extra pumping laser and WDM couplers needed. In this work, we report on the development of an alternative broadband source made out of a low-cost multimode laser diode, where the light comes out of a piece of single-mode fiber for easier coupling to the external fiber system.

2- DEVICE DESCRIPTION

The proposed structure is shown in Fig. 1. The reflectivity of the external facet of a laser diode is set to a minimum value ($R_2 \approx 0$) by depositing an appropriate anti-reflection (AR) coating. The laser cavity is then rebuilt by adding a piece of single-mode fiber with a microlens at the its edge for optical coupling to the laser diode. The resulting device can be modeled as a three-mirrors laser cavity (R_1 , at the internal facet, R_2 , at the pigtail, and R_3 , at the fiber end).

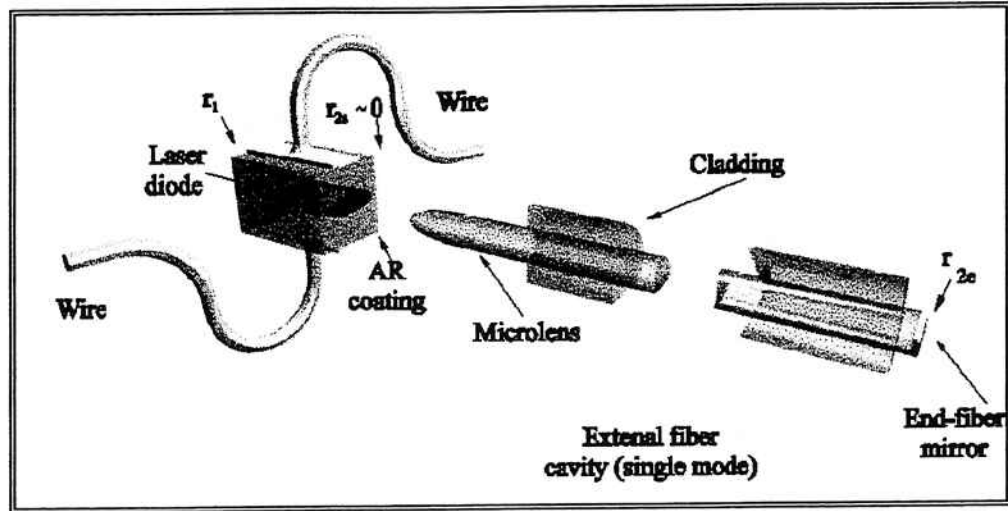


Fig.1: Laser diode operating with an external fiber cavity

A theoretical treatment for a similar problem is well developed in the Peterman's book on semiconductor laser diodes[4]. The difference here is that the low reflectivity mirror is the second one. Hence, this work follows a similar reasoning to Ref. [4]. As the main interest is the comparison of the number of allowed modes in the original laser diode and in the extended cavity system, it is necessary a relationship between the mode separation with $(\delta\lambda_2)$ and without the external cavity $(\delta\lambda_1)$:

$$\frac{\delta\lambda_1}{\delta\lambda_2} = 1 + \frac{n_f L_f}{n_c L_c}$$

where n_f and n_c are respectively the fiber and the laser diode cavity refractive indexes, and L_f and L_c are the fiber external cavity and the diode cavity lengths. This equation allows to predict that there are many more modes with the external cavity than with the original laser cavity, for a given bandwidth, since $L_f \gg L_c$. The wavelength-dependent gain $\gamma(\lambda)$ for the system in Fig. 1 can be equaled to

$$\gamma = \alpha_c + \frac{\alpha_f L_f}{L_c} + \frac{1}{L_c} \ln \left(\frac{(k_{ext})^2}{R_1^2 R_2^2 (1 + 2k_{ext} \cos(\theta))} \right),$$

and expresses how many modes in fact may oscillate for a given total cavity loss, assumed to be approximately wavelength-independent, since only when the gain is enough to cope with the cavity loss the laser mode will oscillate. Ultimately, the loss level in the cavity round trip will determine how much of the available bandwidth

allowed by the laser cavity material (typically 60 nm for GaAs laser diodes at the 0.78-0.85 nm wavelength range) will have oscillating modes. In that equation, α_c and α_f are respectively the losses per unit length for the diode cavity and the fiber. The parameter k_{ext} , given by

$$k_{ext} = R_2 / \left(R_3 (1 - R_2^2) \exp(-2\alpha_f L_f) \right),$$

appears in the solution of the three-mirror cavity problem.

3 - DEVICE FABRICATION

The fabrication starts by opening up the laser diode case to expose the laser facet where the AR coating is to be deposited. The laser is then placed into an evaporation chamber. In order to monitor on-time the optimum film thickness for a perfect anti-reflection action at the operating wavelength, a monitoring system was built, as depicted in Fig.2. The laser diode is driven by a sum of a bias current plus a senoidal current in such way that the total current being applied to the laser sweeps from 0 to a maximum current.

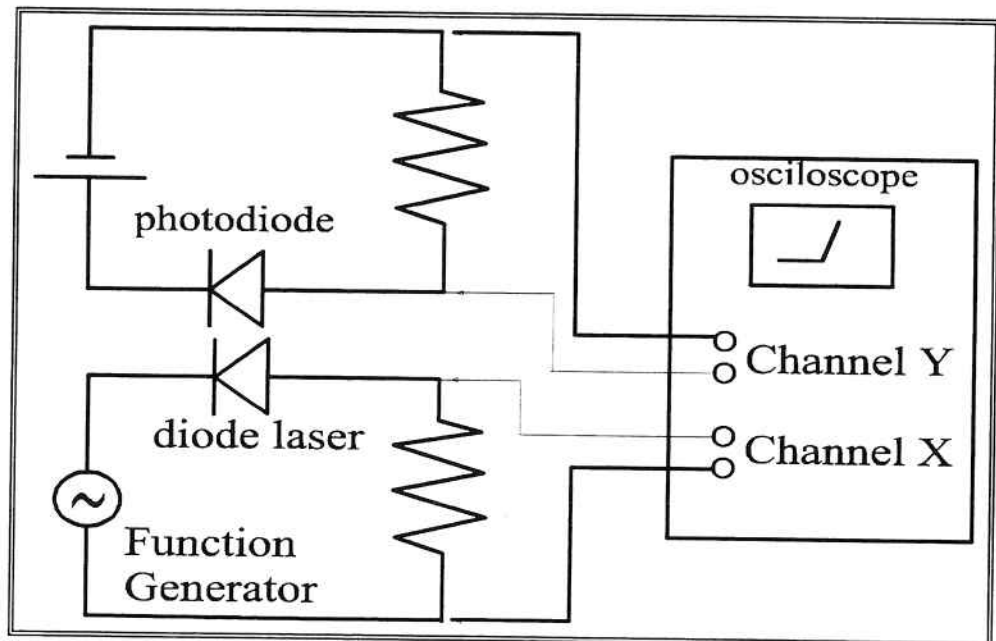


Fig. 2.a- Diagram of the on-time monitoring system for the proper AR coating thickness;

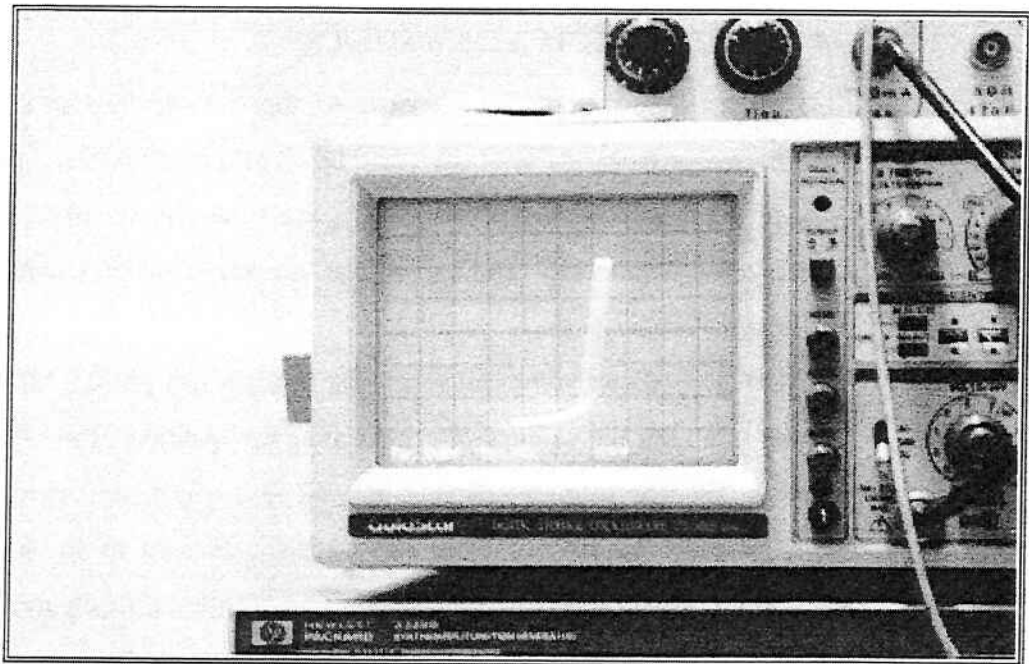


Fig. 2b - Emitted power versus applied current curve (P_xI) to be monitored as the film grows;

A signal proportional to that current feeds the x-channel of an oscilloscope. Simultaneously, the output power is monitored by the photodetector signal injected in the y-channel. It is possible then to measure on-time the P_xI curve as it changes by the film deposition (Fig 2.b). The slope of the P_xI curve decreases as we approach the point where the optimum film thickness has been deposited. The process is stopped at the minimum observable slope. The laser behaves then as a LED.

One end of the piece of fiber to be the external cavity is drawn by a fusion arc into a round shape to make a microlens at that fiber tip. The other end is polished and put into the evaporation chamber to make a partial mirror at the tip. The mirror reflectivity can be measured accurately by simultaneously depositing the same film onto a silica slab to be used as a test sample afterwards. When everything has been done, the fiber is precisely positioned at the laser external facet for maximum power coupling.

4 - EXPERIMENTAL RESULTS

The experimental set-up used to test the devices is shown in Fig. 3. The positioning system, the laser drive and temperature controller, a microscope focused on the pigtail area to avoid the accidental contact between the microlens and the laser facet during the alignment, and an optical spectrum analyzer with 0.1 nm wavelength resolution can be seen.

Fig. 4 shows a typical result for a 1mW Mitsubishi ML42A multimode laser diode, for both the original laser and after the addition of a 1.0 m long external fiber cavity. The spectrum broadening as well as a slight shift in the central wavelength observed are due to the higher carrier density caused by the higher injection current applied to compensate for the increased cavity losses. Compared to the original laser, the power is distributed amongst many oscillating modes very closely spaced. As the analyzer resolution is greater than the mode spacing, the new spectrum looks like smooth without spectrum modulation, which is usually seen in the SLD sources commonly employed in fiber gyros.

Fig. 5 shows the P_xI curves for both cases. The threshold current is approximately the double for the laser with external cavity, which implies that in the new system the loss is about 3 dB higher than in the original laser cavity. The main loss mechanism comes from the coupling between the fiber and the laser.

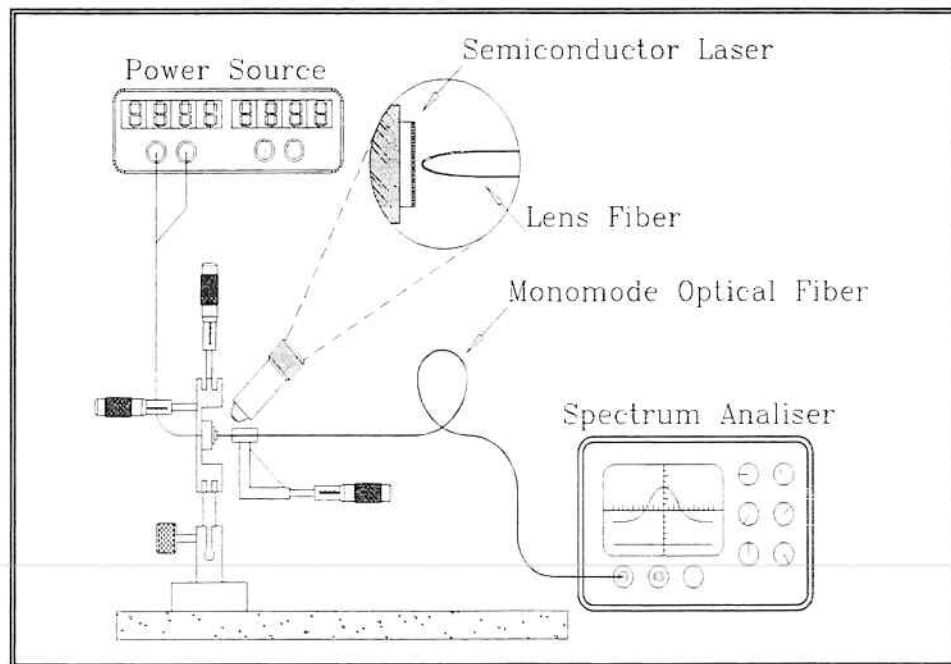


Fig. 4: Experimental set-up used.

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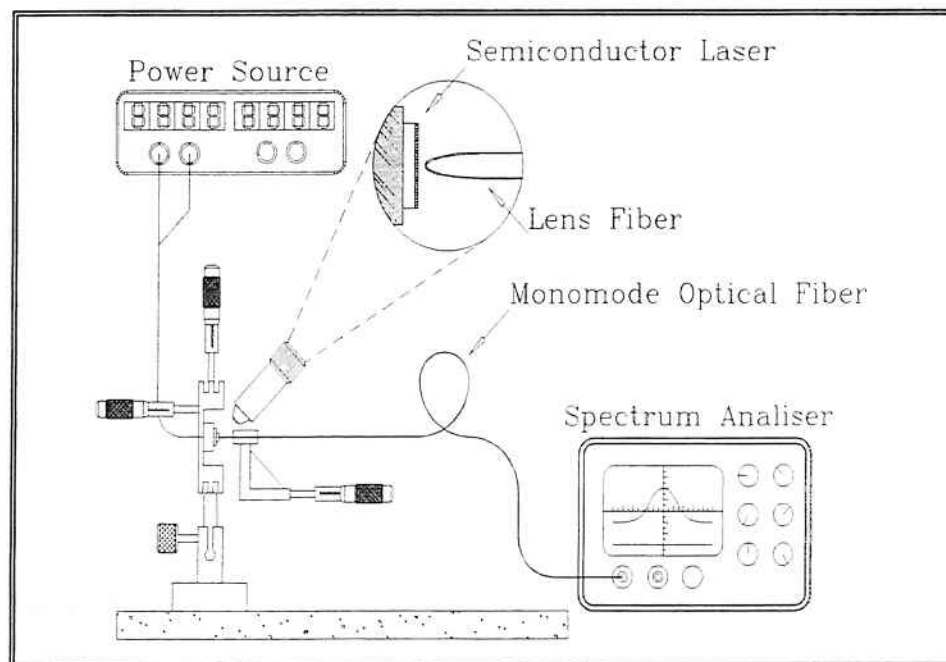


Fig. 4: Experimental set-up used.

One problem faced is that the new structure has to be operated at higher current levels. This brings in the problems of increased power dissipation, increased leakage current from the laser active region (causing optical power saturation), and the heating of the laser original cavity, which may change slightly the optimum positioning of the fiber tip for the best optical power coupling to the fiber. Limits may have to imposed on the maximum current and thus the maximum power obtained for a particular laser, so that higher power laser diodes withstanding higher currents are good candidates for spectral broadening.

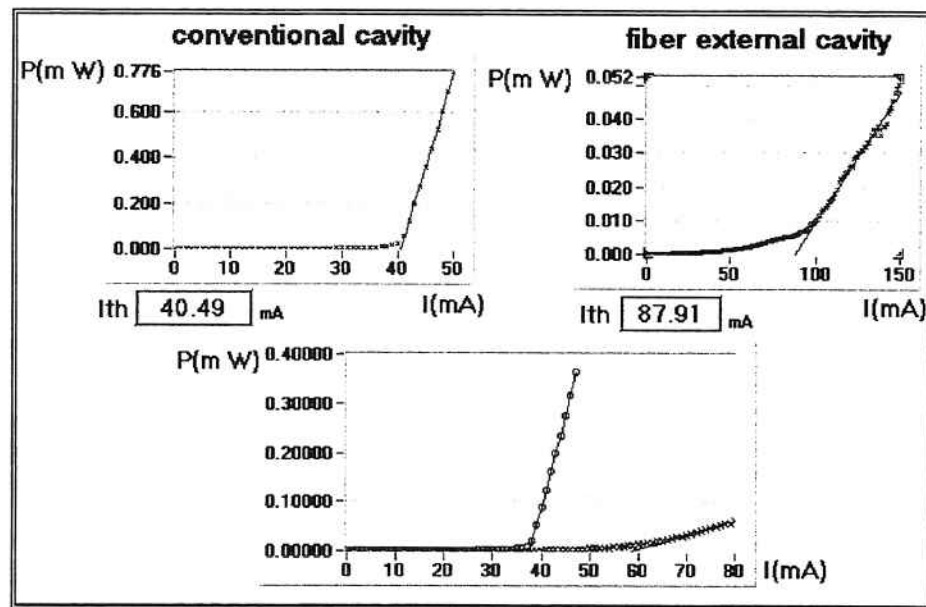


Fig 5: Spectral broadening of a laser diode with a 1.0 m long external cavity;

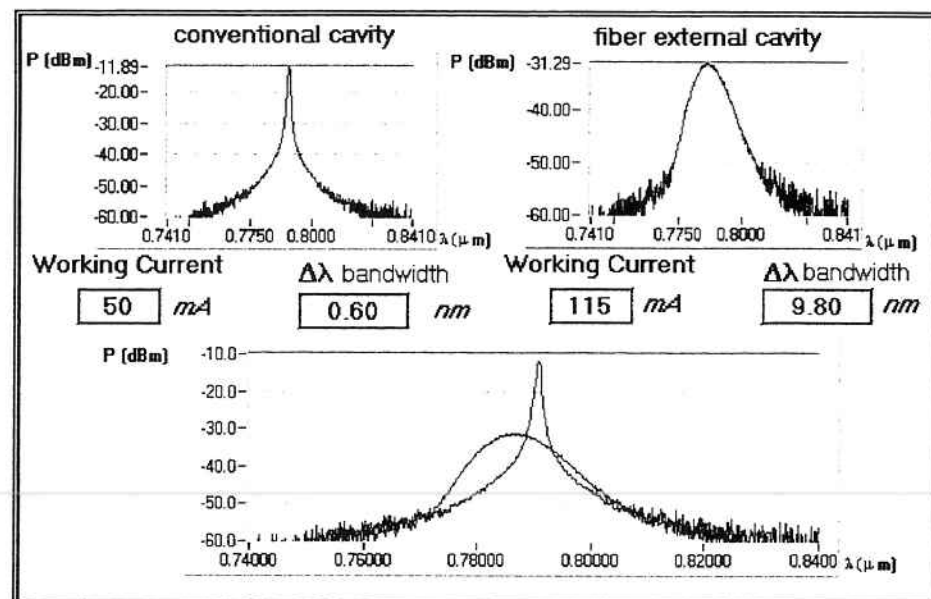


Fig. 6: Power versus current curves for the original and the new laser structure.

5 - CONCLUSIONS

Broadband laser sources made out of low-cost laser diodes that emit light already in the single-mode fiber fundamental mode were demonstrated. Compared to other types of broadband sources, it has shown a spectrum bandwidth of about 10 nm with no spectral modulation and optical power of about 100 microwatts coupled to the fiber. We believe we can improve those figures by proper selection of the laser diode to be used and by applying an AR coating at the microlens as well as by making a stable pigtail to minimize losses in the extended cavity. This would make this type of source very attractive for cost-effective production of fiber-gyroscopes.

6 - ACKNOWLEDGEMENTS

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