Low noise Planar External Cavity Laser for Interferometric Fiber Optic Sensors

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ABSTRACT

A 1550 nm DWDM planar external cavity laser is demonstrated to provide low phase /frequency noise and narrow linewidth. The cavity includes a semiconductor gain chip and a planar lightwave circuit waveguide with Bragg grating, packaged in a 14-pin butterfly package. The laser shows linewidth < 30 kHz and phase/frequency noise comparable with that of long cavity fiber lasers. Performance is suitable for various fiber optic sensing systems, including interferometric sensing in Oil and Gas, military/security and other applications, currently served mostly by costly and less reliable laser sources.

1. Introduction

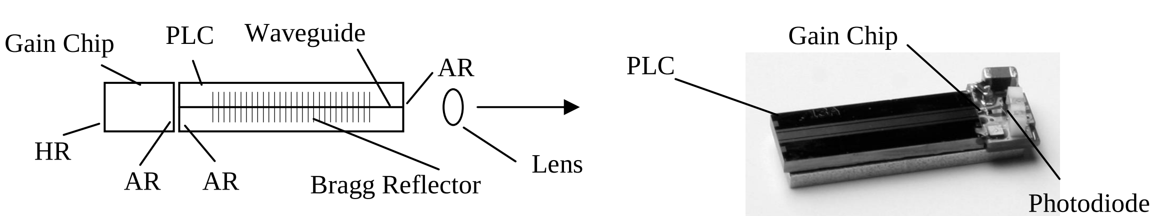
The interferometric technology for fiber optic distributed sensing for obtaining high quality dynamic measurements was developed for the past 15 years, but only now is moving into the market deployment stage. Due to intrinsic high cost, applications are mostly in either military surveillance or remote sensing in severe environments (sub-sea or subsurface for the oil and gas industry), where cost sensitivity is not necessarily the first priority. These two markets, which do not nearly represent the overall potential markets, are now looking for cost/performance optimization. Other markets that are more price sensitive, include distributed structural monitoring, large area and perimeter surveillance, seismic monitoring, and communications systems security. These markets would embrace fiber distributed sensing solutions if they are proven cost effective. Interrogators represent the dominant cost portion of the overall interferometric system cost, where low phase noise lasers typically represent the highest cost element of the interrogator. Currently only buried short-range terrestrial security interferometric systems with frequency noise requirements of < 3000 Hz/Sq. Hz @ 100 Hz and < 500 Hz/Sq. Hz @ 1000 Hz can use Telecom or CATV grade DFB lasers. All other applications with significantly more demanding frequency noise requirements are using high cost fiber lasers or other multi-component sources with limited cost and size reduction potential.

External Cavity Laser (ECL) technology is an attractive low cost laser solution for interferometric sensing applications. Compared with DFBs, ECLs have significantly narrower linewidth and lower frequency noise due to the long cavity. Hybrid ECLs based on Fiber Bragg Gratings (FBG) have been studied for interferometric sensing applications and demonstrated good phase noise performance[1]; however, they suffer from FBG sensitivity to vibration.

We report here a low frequency noise and narrow linewidth 1550 nm DWDM ECL based on planar Bragg gratings (PBG) on silica-on-silicon planar lightwave circuit (PLC). This cavity structure offers a significant reduction in vibration sensitivity over other ECL designs.

2. Planar ECL Design

A schematic diagram of a planar ECL device is shown in Fig. 1a. The cavity is formed by coupling light between the anti-reflection (AR) coated facet of an InP gain chip with and AR-coated waveguide grating on a PLC.



a b

Fig. 1: (a) Schematic diagram of ECL; (b) Photograph of planar ECL sub-assembly

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The optical coupling between the InP gain chip and the PLC is a critical aspect of the laser cavity construction. Longitudinal stability of the cavity is critical to stabilize the phase of the ECL cavity mode to optimize performance during ECL operation over case temperature and over the lifetime of the device. Fig. 1b shows a photograph of the attached ECL cavity sub-assembly. The sub-assembly is integrated in a standard 14-pin butterfly package on top of a thermoelectric cooler (TEC). Thermo-opto-mechanical design insures minimal temperature gradient, and minimal stress on the cavity over a wide operating case temperature range from -15 to 75ºC.
The optical output beam from the ECL cavity is collimated before going through a double-stage isolator then focused onto either standard or polarization-maintaining single mode fiber. The output optical train of the ECL is designed and assembled using proven methods commonly used in commercial DFBs. The ECL laser is pin-to-pin compatible with commercial DFBs.

3. Test technique description and outline of the test set up.

Outline diagram of the test setup is shown in Fig. 2

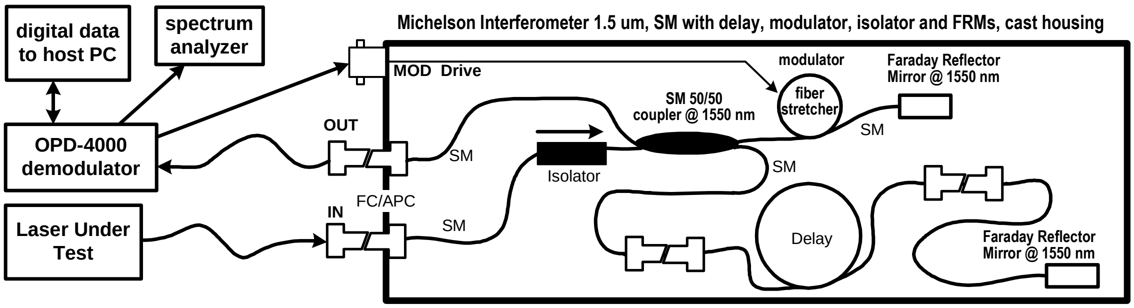

Fig 2.

It includes path mismatched Michelson interferometer with FRM elements to insure high interferometric visibility. Internal connectors are implemented to allow placement of different delay lines (replaceable delay) so that different optical path mismatches may be inserted into the interferometer.
An Optiphase, Inc. OPD-4000 Optical Phase Demodulator [2] is used to measure the optical phase in the mismatch path interferometer. Demodulation at a 70 kHz rate is accomplished by a phase generated carrier stimulus followed by true-phase digital demodulation. With low self-noise (few µrad/rt-Hz), this approach is capable of laser phase/frequency noise measurements of the lowest noise lasers commercially available.

4. Experimental Results

Typical ECL Light/Current characteristics and time-averaged spectrum, obtained with OSA, are shown on Fig. 3. The ECL device has very high SMSR (> 50 dB). Linewidth was less than 30 kHz, when measured with self-heterodyne technique.

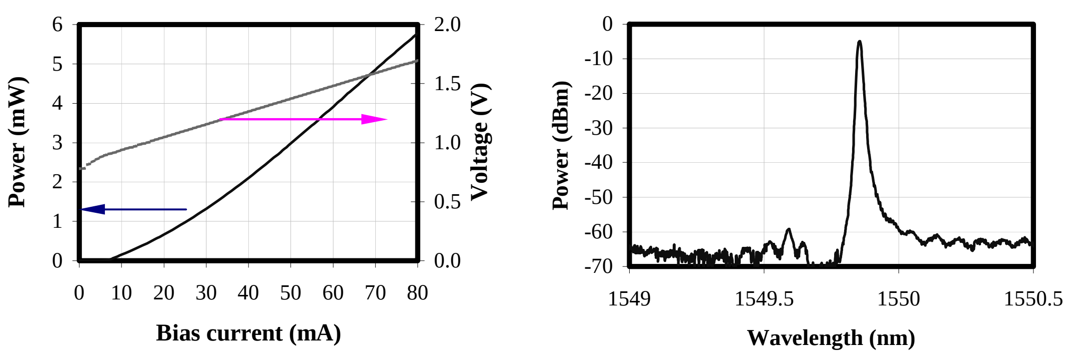

Fig. 3 ECL LIV and Spectrum

Phase/frequency noise performance is shown on the Fig. 4. Phase noise values are normalized to the 1 m interferometer optical path difference (OPD). The peaks visible on the phase/frequency noise spectral density characteristic are at 60 Hz and multiples of 60 Hz are a result of AC leakage in the ECL bias current source and demodulator. The ECL was fabricated using gain chip and PLC designed for high-speed Telecom applications. Optimization of the planar ECL will further improve performance on phase noise, linewidth and output power.

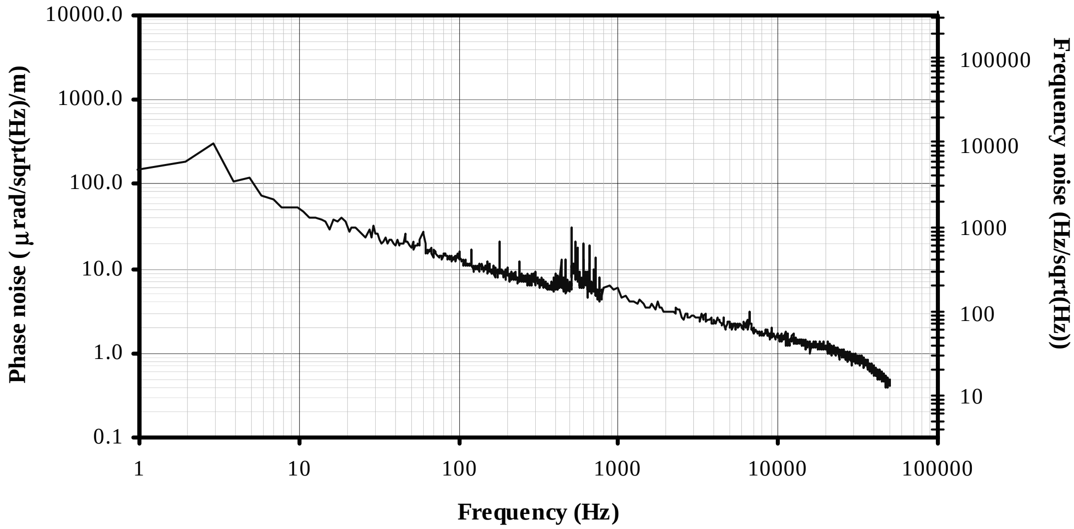

Fig. 4. ECL Phase/Frequency noise spectral density.

Long-term operation under demanding environmental stress conditions is an important requirement for the laser, in order to be suitable for sensing applications. All sub-components and packaging technology for the planar ECL have been previously Telcordia qualified for Telecom applications. The laser has shown excellent wavelength stability and consistency of the other performance parameters over long-term operation and over case temperature range. Additional requirements, specific to many applications, is operation under vibration and acoustic noise.

The planar ECL cavity is intrinsically stable compared to FBG based fiber lasers and ECLs due to the polarization preserving waveguides fabricated on solid-state Si substrate. All possible vibration sensitivity is package related, and is resolved by proper integration of the cavity sub-assembly inside the 14-pin butterfly package. Normalized vibration sensitivity of planar ECL in the 0-300 Hz vibration frequency range is presented in Fig. 5.

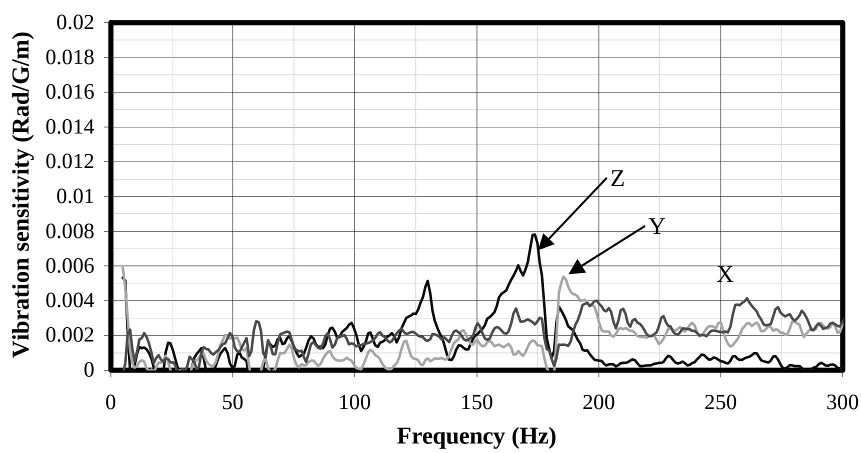

Fig. 5. ECL Phase noise vibration sensitivity

5. Performances analysis and suitability analysis for various applications.

The chart in Fig. 6 shows normalized phase noise of various laser types (DFB, planar ECL and two performance grades of Fiber Lasers) used for remote interferometric sensing. As shown, the phase noise performance of the planar ECL is approaching the performance of the typical (“3 kHz”) fiber laser, which indicates a high performance capability and suggests suitability for a wide range of distributed sensing applications.

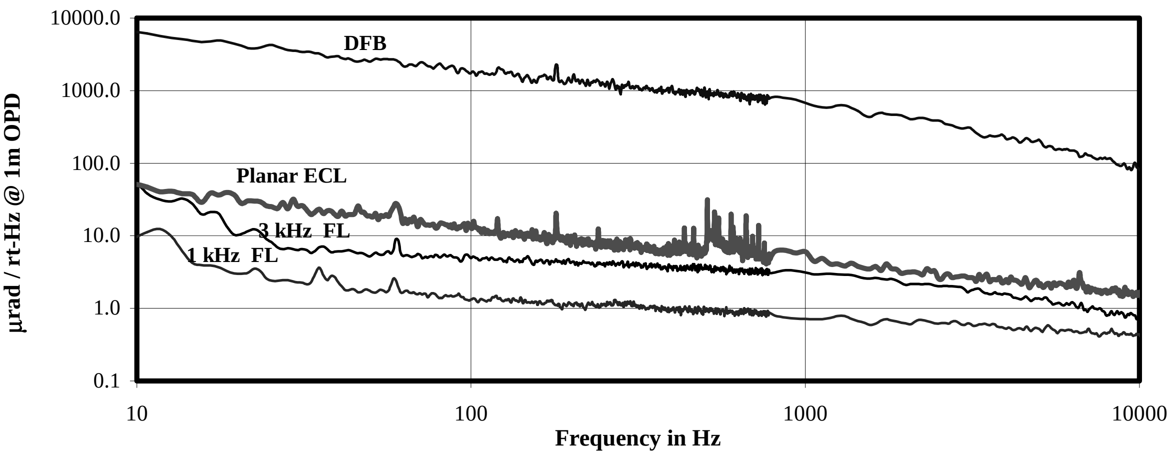

Fig 6. Phase noise comparison of the various lasers

Planar ECL has been designed in a Path Compensated TDM interrogator and tested in the field trial in a distributed buried sensing application. It provided high performance, comparable with that of a 3 kHz fiber laser, which was also tested in the same system.

As there are various design approaches for multi-channel interferometric interrogation, and fiber sensor designs can offer a wide range of sensitivity, it is helpful to segregate interferometric interrogation into two general classes: Path Compensated TDM (PCTDM) and Path Mismatch Multiplexed (PMM).
Our view on Planar ECL application suitability is presented in the Table below.

Application	PCTDM	PMM
Physical Security (perimeter or boundary, buried or fence deployed)	all	most
Civil Structure monitoring	all	most
Oil and Gas (down-hole, sea-bed, streamers)	all	some
DOD marine surveillance (most active and passive apps)	most	some

Note that the applications identified above can sometimes utilize a very large sensor count (some into the thousands). Both PCTDM and PMM interrogation approaches are compatible with TDM/DWDM multiplexing to attain these high channel counts. When these systems demand multiple wavelengths there is a significant advantage to the use of the planar ECL due to its low cost and high reliability when compared to fiber lasers.

6. Conclusions

For the first time, a narrow linewidth and low phase/frequency noise 1550 nm DWDM planar waveguide based ECL was developed to satisfy most of the interferometric sensing performance requirements in a small package, providing high stability, reliability and low cost. Results show that planar ECLs are suitable for most of the interferometric applications with demanding environmental conditions.

References

[1] Robert E. Bartolo, Clay K. Kirkendall, Vladimir Kupershmidt and Sabeur Siala. “Achieving narrow linewidth, low phase noise external cavity semiconductor lasers through the reduction of 1/f noise”. *Novel In-Plane Semiconductor Lasers V, edited by Carmen Mermelstein, David P. Bour, Proc. of SPIE Vol. 6133, 61330I, (2006) ·*

[2] Optiphase, Inc. Website (ref to OPD-4000) www.optiphase.com