Development of a single-mode cost-effective pumping scheme

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***Abstract*—In this article, a new architecture for broad-area laser diode on glass platform is proposed. It is composed of a planar mode converter made by ion-exchange on glass and a Fiber Bragg Grating and provides a single-mode and wavelength selective optical feedback in the multimode pump laser. The spectral locking of the laser diode is experimentally demonstrated with a side mode suppression ratio superior to 25 dB for an injection current inferior to 1 A.**

Integrated optics on glass, wavelength stabilization, single-mode stabilized pumping scheme

I. Introduction

Ion-exchange on glass is a well-established technology for sensor applications. Its compactness and stability allow schemes of integration that often reduce costs of fabrication and improve performances or security. It has already been used for bio-detection[1], displacement[2] or orientation measurement[3]. Applications in avionics are currently in development since the measurement of an aircraft's True Air Speed (TAS) has been recently demonstrated using a LiDAR containing several ion-exchanged integrated optics elements[4]. This system, supported by the European Community presents modes of failures that are different from the traditional anemo-barometric module. The required features are reliability, compactness, low power consumption and controlled costs. In this work we propose a solution to increase the optical pump power in order to suppress the booster presently required.

Three types of compact pump power are commercially available. The first one consists of a narrow stripe semiconductor laser coupled to a single-mode fiber Bragg grating (FBG) which stabilized the emission wavelength. These sources present a single-mode emission that is well centered at the maximum of the active medium absorption band. Their low-frequency intensity noise is also reduced. However these devices can suffer from catastrophic optical mirror damage (COMD), which limits the maximum achievable output power to 700 mW since the laser facets are damaged under a too high power density[5]. A way to overcome the COMD is to increase the emitter width, decreasing thus the power density. This second type of devices is called broad area laser diodes (BALD) and achieves reliable power emission up to 35W[6]. The pump beam is however multimode and the emission spectrum is a few nanometers wide. A third architecture consists in inserting a taper in the active region. The narrow region acts like a modal filter and ensure a single-mode emission whereas the wide region decreases the power density at the output facet. An output power of 8W has already been demonstrated[7]. However, the price per watt is clearly to the advantage of a BALD structure. Though transverse multimode pumping schemes for single-mode planar operation have already been successfully used for amplification[8] and lasers[9], they were using expensive hybrid glasses and suffered from the low overlap efficiency between pump and signal modes.

We propose in this article a new architecture based on cost-effective multimode pumps. The design, which aims at locking the BALD emission on its fundamental transversal mode, is presented in section II. The realization of the glass device and the optical characterization of the first prototype are then detailed in section III before a conclusion.

II. Design

The aim of the proposed architecture is to lock a BALD emission on its fundamental transversal mode. As schematized in Fig. 1, the multimode pump emission is coupled in a mode converter whose narrow end is single-mode. A butt-coupled FBG provides a wavelength and mode selective feedback in the BALD. The aim of the external cavity is to boost the fundamental mode emission and to stabilize the emission spectrum around the Bragg wavelength.

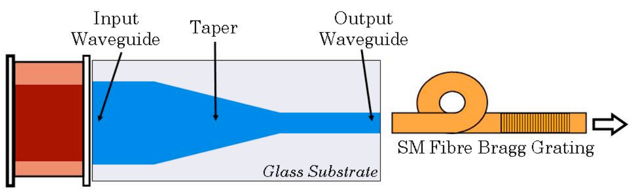

Figure 1. Fundamental mode locking and wavelength stabilization

The output of the mode converter must be designed to ensure single mode operation and minimum coupling losses with optical fibers. It can be achieved with a thermal ion-exchange. This requirement contrasts a priori with the high confinement required at the input waveguide implying a Field Assisted Ion Exchange (FAIE). To overcome this issue, a dielectric mask can be locally deposited on the rear side of the chip, beyond the output waveguide, in order to partially screen the electric field. This single-step technique has already proven its efficiency and adiabaticity for deep selectively-buried waveguides[10]. Simulations have been carried out in order to fix the ion-exchange processes parameters. The electric field has been fixed at 0.1 V/µm and the exchange time at 7 min. The diffusion aperture of the output waveguide w has thus been chosen in order to optimize the butt-coupling with a standard HI1060 FLEX fiber. The most adapted diffusion aperture appears to be $w = 2.0$ µm with coupling losses around 2 dB. The third part of the design concerns the tapered central zone. The Burns & Milton criterion gives a theoretical condition to design an adiabatic transition[11]. For a taper whose input section is 100 µm wide and assuming an effective index of 1.55, the critical half-angle is 0.18. The length of a linear taper must then be greater than 16 mm. The mode converter chosen is a transition of 20 mm long from the lithography window $w = 100$ µm to $w = 2.0$ µm.

III. Realization and Characterization

A 1.5 mm thick commercial silicate glass substrate is first cleaned with a basic solution. An 80 nm thick alumina mask is deposited by sputtering and the waveguides patterns are inscribed in the mask by photolithography. A polymer film is placed on the rear surface of the glass plate perpendicular to the apertures, in order to screen the electric field on the output waveguide side. A selective FAIE, in a molten salt with a molar concentration of $0.5AgNO_3$-$0.5NaNO_3$, is then realized during 6 min 30 s at a temperature of 270 °C under an applied voltage of 150 V. After removal of the masks, the device is diced and its facets are polished.

The realized glass mode converter is butt coupled to the diode on an optical bench. A commercial FBG, with a reflectivity of (81 ± 3)% collects the light supported by the single-mode output. The FBG output light is then coupled in an optical spectrum analyzer Anritsu MS9710B. Fig. 2 represents the laser diode's direct emission spectrum on the left and the emission spectrum of the device on the right for different injection currents. The BALD emission is stabilized in the spectral band reflected by the grating. Under the threshold of 240 mA, we see the Bragg spectrum in the ASE of the laser. The spectral locking is then obtained by increasing the current. It is characterized by a maximum Side Mode Suppression Ratio (SMSR) of (33.06 ± 0.14) dB at $I = 500$ mA. This ratio is superior to 25 dB for $I < 1$ A. For $I < 2$ A, other laser peaks appear around 981 nm, where the gain of the SC is maximum. The evolution of SMSR can be explained as follows: with the increase of the current, the mode competition in a homogeneous medium allows the preeminent mode to get the energy of the other modes. However, at high power densities the non linear gain suppression leads to a smaller gain discrimination[12]. This effect can be reduced using a smaller detuning between maximum gain peak and Bragg reflectivity. Indeed this value reaches 2 nm at $I = 2$ A in our device.

We also measured the frequency shift with current. We report a shift of -12.0 GHz/100mA, which is five times lower than the BALD's direct emission. The total shift over the 2 A current range is 1.2 nm, which is included in the spectral width of Ytterbium absorption of the seed DFB laser.

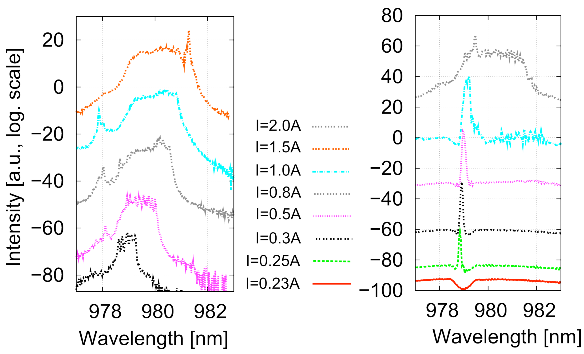

Figure 2. Emission spectrum of the solitary laser diode on the left and of the system on the right for different injection currents.

IV. Conclusion

A new architecture for the integration of broad area laser diode on a glass platform has been reported. Composed of a planar mode converter made by ion-exchange on glass and a FBG, it provides a single-mode and wavelength selective optical feedback in the BALD. It boosts the fundamental emission of the diode and stabilizes its emission spectrum on the Bragg wavelength. We first presented the design of the mode converter. It uses a single-step ion-exchange process whose input and output are respectively adapted to the laser diode and the optical fiber butt-couplings. We demonstrated the spectral locking of the laser diode with a SMSR superior to 25 dB for an injection current inferior to 1 A.

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