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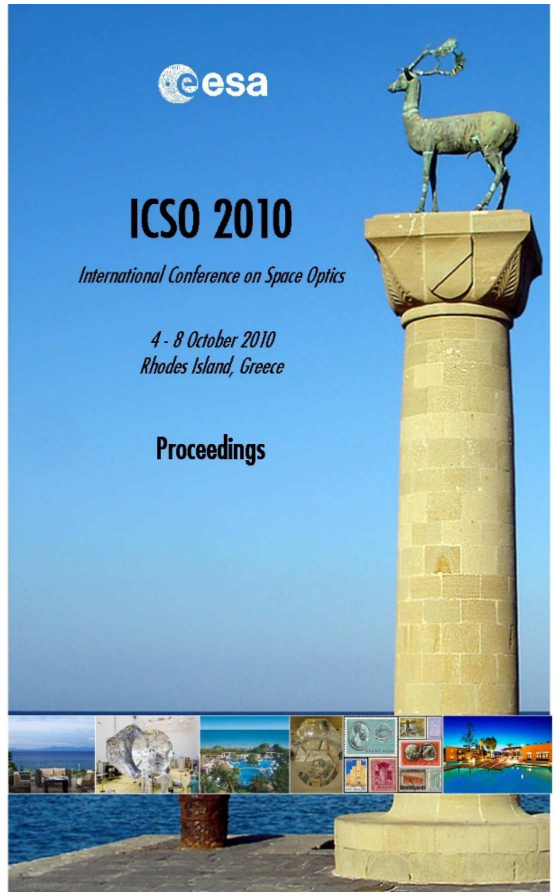

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HIGH POWER AL-FREE FABRY-PEROT AND DISTRIBUTED FEEDBACK LASERS DIODES FOR RUBIDIUM PUMPING

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I. INTRODUCTION

Since a few years, atomic pumping technology has spread a lot, in particular for applications like very sensitive and stable atomic clocks, gyrometer, gradiometer, and gravimeter. Development of a compact optical source with a high power and a very narrow linewidth has become very important. At the moment, using an extended cavity laser (ECL) is a common solution in laboratory. For integrated system in spaces applications which need an excellent mechanical stability, the distributed feedback laser diode could be a good alternative.

In this paper, we will present the performances of two kinds of lasers: Fabry-Perot laser diode (FP) and distributed feedback laser diode (DFB), centered at 780nm, for the pumping of the D_2 line of Rubidium atoms (Rb). The Fabry-Perot laser diode presents the advantage of a high power emission but with a multimode optical spectrum. It can be integrated in an extended cavity which permits to filter the frequency and therefore to obtain a very narrow linewidth (less than 100 kHz). The DFB laser has the advantage to show a single frequency emission thanks to the integration of the filter in the device waveguide.

II. LASER DIODE STRUCTURE

In this paper we present different results obtained from an Alumium-free laser. The use of an GaInP active region offers an attractive alternative to the conventional AlGaAs-based design with the possibility to easily avoid oxidised AlGaAs-compounds on mirror facets [1] and catastrophic growth of dark line defects under high power operation [2]. Aluminium-free devices can hence benefit from a longer device lifetime and better reliability[3]. We have demonstrated a high reliability and a narrow linewidth for Al-free DFB laser at 852nm for Cesium pumping [4].

We design the laser structure (Fig. 1) to be a separated confined heterostructure. The quantum well in GaAsP has been surrounded by two layers of GaInP to form the optical cavity. The cladding is composed of AlGaInP. For the DFB structure we insert in the p-cladding a second order grating in GaInP/GaAsP/GaInP. These structures were realized by metal-organic chemical vapour deposition (MOCVD.)

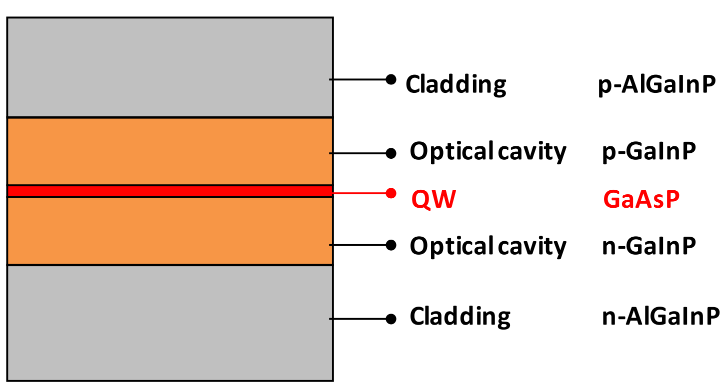

Fig. 1: Schema of Al-free DFB SCH

4µm shallow ridge waveguides (RW) were defined using standard photolithography techniques and inductively coupled plasma (ICP) etching.

III. FABRY-PEROT LASERS DIODES PERFORMANCES

In this part, we will present the results of Fabry-Perot (FP) laser diode usable in extended cavity. Our lasers have a length of 1mm with an anti- and highly- reflective (AR/HR, respectively 2% and 95%) dielectric coatings on respectively the front and rear facets. All measurements have been made at a temperature of 20°C, under continuous wave operation.

A. Light-current characteristics

We can see (Fig. 2) the light-current (L-I) characteristic (red curve) and voltage current (V-I) of our FP laser measured at 20°C.

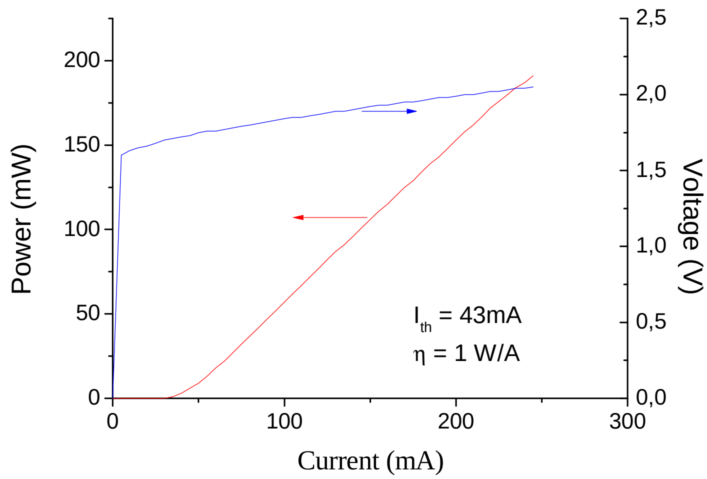

Fig. 2: L-I and V-I characteristics for an AR/HR Fabry-Perot laser diode at 20°C

We obtain a low threshold current around 43mA with a high external differential efficiency of 1W/A. We don't observe any discontinuous aspect along the curve and we obtain a power of 190mW at 250mA. The blue curve represents the V-I characteristic of the FP laser diode. The turn on voltage has been measured at 1.65V and the series resistance extracted from the linear regression of this curve is around 1.9Ω.

B. Beam Quality

To calculate the beam quality, or quality factor M^2, of our FP lasers diodes, we have first measured the near field and far field of the laser then, with the width of both measurements at $1/e^2$, we determinate the M^2 using (1):

$$M^2 = \frac{\pi}{\lambda} w_{1/e^2} \theta_{1/e^2} \quad (1)$$

where w_{1/e^2} and θ_{1/e^2} are respectively the half width at $1/e^2$ of the near field and the far field and λ the wavelength.

We can see (Fig. 3) the beam near field at 20°C, 200mA (around 150mW) in the plane of the layer (or slow axis) and the beam far field (Fig. 4) at the same operating condition.

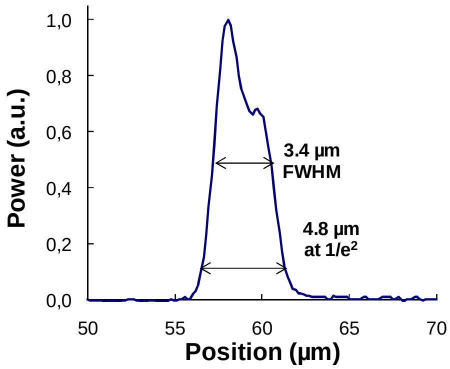

Fig. 3 : Near field of FP laser with AR/HR coating at 20°C, 200mA, P=150mW

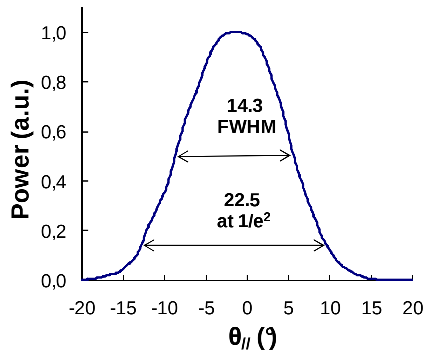

Fig. 4 :Far field of FP laser with an AR/HR coating at 20°C, 200mA, P=150mW

We obtain a divergence of 22.5° at 1/e² and we can note the good quality of the single transversal mode. The representation of the near field (Fig. 3) shows a width of 4.8µm at 1/e². From these values, we obtain a good M² around 1.9 at 150mW.In the fast axis, we obtain a divergence of 68° at 1/e².

These kinds of laser are good candidate to be integrated in an extended cavity.

IV. DISTRIBUTED FEEDBACK LASERS DIODES

Now, we present our result on distributed feedback (DFB) lasers diodes. The different characteristics of our DFB laser are the following: a length of 2mm, a ridge waveguide of 4µm, a grating coupling factor multiplied by the cavity length K.L designed for a value of 1.5 and an AR/HR dielectric coating on the facets.

A. Light-current characteristics

As we can see in this L-I characteristic (Fig. 5), we obtain a DFB laser with a threshold current around 70mA at 25°C with a slope efficiency of 0.37W/A.

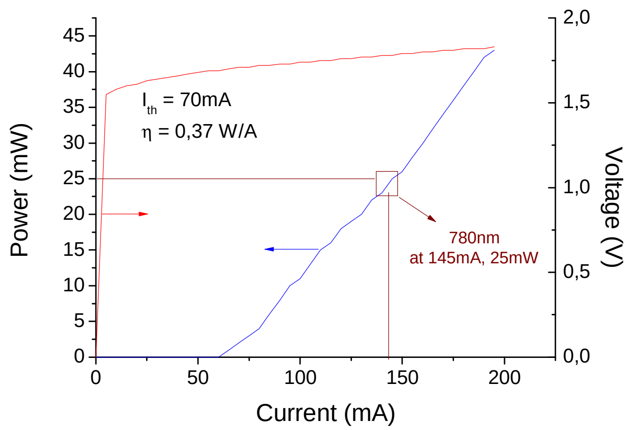

Fig. 5: L-I and V-I characteristics of an AR/HR DFB laser at 25°C

The V-I characteristic shows that the turn on voltage is around 1.63V and the series resistance of 1.05Ω. We have obtained the D_2 line of Rb (780nm) at 25°C with an optical power of 25mW. Compare with the FP laser diode, the threshold current of the DFB laser is higher. Two raisons can explain that: first is the fact that the DFB laser is longer than the FP laser (2mm vs 1mm). Second, due to the integration of a grating in the structure, the total losses increase. For these, the slope efficiency of our DFB laser decreases too.

B. Beam Quality

We also measured the beam quality of the DFB laser present previously. Figures 6 and 7 show the result of respectively the near field and far field at the D_2 line of Rb.

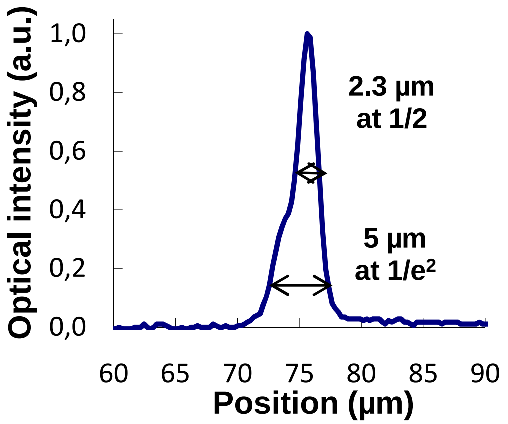

Fig. 6: Near field of an AR/HR DFB laser at the D_2 line of Rb (780nm) at 25°C, 25mW

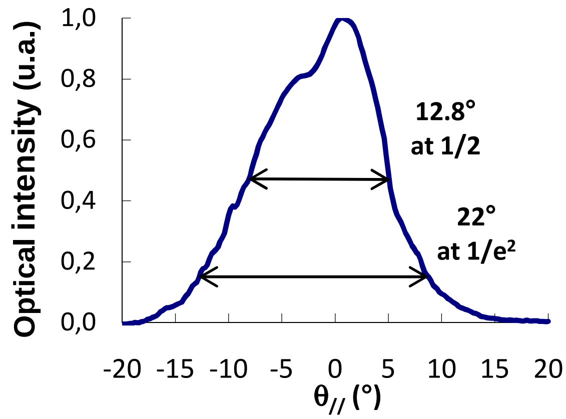

Fig. 7: Far field of an AR/HR DFB laser at the D_2 line of Rb (780nm) at 25°C, 25mW

We obtain a width at the facet of our laser of 5µm (at 1/e²) at 25°C and 25mW. The beam divergence in the slow axis is around 22° at 1/e². The beam quality factor resulting of the calculation is 1.9. We can notice that all these values are the same for DFB and FP laser diodes.

C. Single longitudinal mode at D2 line of Rb

In order to check the single frequency behavior together with the emission at the R_b D2 line (780nm), we measured the optical spectrum (Fig. 8) by coupling the beam with an optical fiber and injected it in an optical spectrum analyzer.

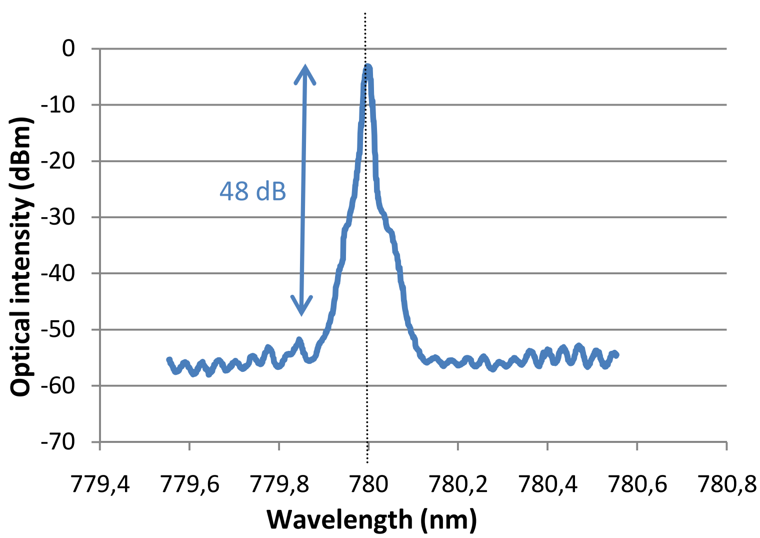

Fig. 8: Optical spectrum at the D_2 line of Rb for an AR/HR DFB laser at 25°C, 25mW

We obtain the D2 line of Rb for the temperature and current conditions of 25°C and 140mA, the optical power corresponding is 25mW (see Fig. 5). We observed a very good side mode suppression ratio (SMSR) of 48dB.

D. Linewidth characterization

The spectral linewidths of the DFB lasers were measured using the delayed self-heterodyne linewidth measurement method [5]. This method was developed to carry out the determination of two important parameters of semiconductor lasers such as the linewidth and indirectly the Henry factor. The distributed feedback diode laser output is divided into two paths (Fig. 9). The first path is delayed by time t_0 (10.2 µs) through a single mode fiber, 2 km long. The second path is frequency shifted by a frequency f_{AOM} (80 MHz) that is much higher than the spectral spread to be measured. The throughputs of both paths are mixed by a coupler 50/50 and injected on an avalanche photodiode. When the delay t is much longer than the coherence time of the laser output (factor 5 or 10) the two paths are independent of each other [6]. In these conditions, the relation between the self-heterodyne width at 3dB and the linewidth depends on the kind of noise. The 3dB spectral width is twice the experimental beat value when the spectrum is lorentzian (white noise) and $\sqrt{2}$ times when it is gaussian (flicker noise or 1/f noise) [5,7].

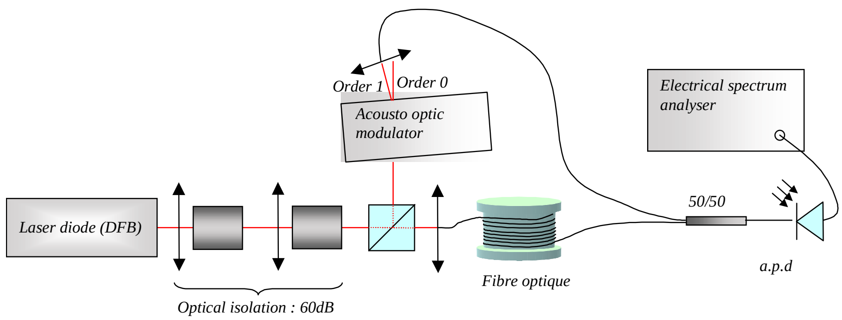

Fig. 9: Schema of the self-heterodyne method

We can determinate the relation between the linewidth of the DFB laser and its length of coherence by using the following formula (2):

$$L_C = \frac{c}{\Delta\nu} \qquad (2)$$

where *Lc* is the coherence length, *c* the light velocity in the fiber and $\Delta\nu$ the linewidth of the DFB. It's mean that for a linewidth of 1MHz, the coherence length is equal to 200 m which gives a delay t around 1µs. By using a 2km fiber, so a delay time of 10.2µs, we are in the condition explained previously.

Figure 10 shows the beat measurement at the Rb D_2 line (dot curve) with its Lorentzian approximation (red curve).

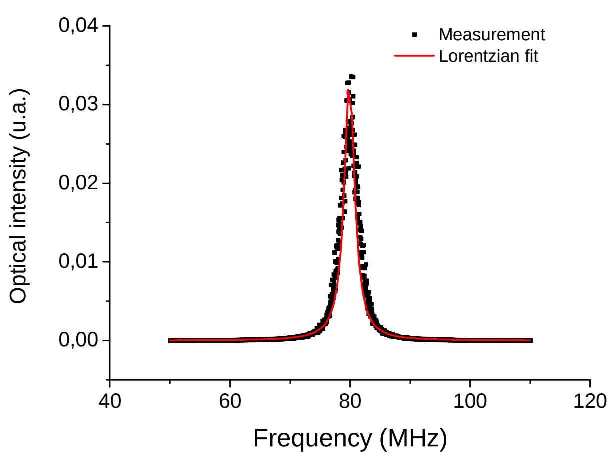

Fig.10: Beat measurement (dot curve) of an AR/HR DFB laser at the D2 line of Rb (25°C, 125mW). The blue curve is a lorentzian fit of the beat measurement.

For the AR/HR DFB presented in this paper, we calculate at the condition for obtaining the D_2 line of Rb, for a white noise approximation, a linewidth of 1.07MHz. If we consider the 1/f noise and we fit this curve with a Gaussian function, we obtain a linewidth around 1.9MHz.

V. SUMMARY

In this paper, we have presented the result of two kinds of laser diodes usable for atomic pumping at 780nm. We realized Fabry-Perot lasers diodes with very interesting performances: high power (more than 190mW at 250mA) with a low threshold current of 43mA and a very high slope efficiency of 1W/A. We also obtained a good beam quality factor of 1.9 at 200mA (150mW). The next step for this laser will be integration in an extended cavity to demonstrate high power together with a narrow linewidth.

We also realized DFB laser centered at 780nm. This wavelength has been obtained at room temperature (25°C) with an optical power of 25mW and a beam quality factor of 2. The linewidth of our laser is around 1MHz for a white noise and 1.9MHz for a 1/f noise. The next step for DFB laser will be to increase the optical power and to reduce furthermore its linewidth.

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