# High Yield, Highly Manufacturable High-Power Wavelength Stabilized DBR Diode Laser

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**ABSTRACT**

This paper reports a DBR High Power Diode Laser (DBR-HPDL) realization, emitting up to 14W CW in the 920nm range. Key feature is the use of a multiple-order Electron Beam Lithography (EBL) optical confining grating, stabilizing on same wafer multiple wavelengths by a manufacturable and reliable technology. In present paper, on the same wafer, three pitches DBR-HPDLs 2.5nm spaced have been demonstrated with excellent characteristics of power, spectral purity and stability. Moreover, excellent uniformity of performances across the wafer with different emitted wavelengths demonstrates the maturity of proposed technology for high yield, high volume laser diode production for wavelength stabilized applications.
**Keywords:** high power, wavelength stabilization, semiconductor laser, Bragg grating

## 1. INTRODUCTION

High power wavelength stabilized diode lasers are key components for many applications requiring stabilized pump laser sources, including 980 nm stabilized multi-emitters pump modules or kilowatt-range direct diode sources exploiting Wavelength Division Multiplexing techniques [1]. Wavelength stabilization integrated in the semiconductor diode chip is an attractive, potentially high yield and low-cost technology if compared with external wavelength stabilization, and several realizations have been reported in literature [2, 3, 4]. Present paper is showing improved performances achieved by High Power Diode Laser integrated with DBR section (DBR-HPDL), implementing multiple-order EBL optical-confining shallow grating on dedicated layer (described in [4]). Present technology demonstrated high power on multiple wavelengths on same wafer, together with tight statistical distributions of device performances across 4” of processed wafer.

## 2. DEVICE DESIGN AND STRUCTURE FABRICATION

A broad-area asymmetric GRIN-SCH DBR high power laser diode emitting around 920nm, already reported in [4], was developed maximizing brightness and wall plug efficiency, for Yr-doped fiber laser effective optical pumping.
High power and narrow far field ($< 57^o \perp \times < 12^o \parallel$, FW@1/e$^2$) were achieved with a wall plug efficiency of 60% by a proper design, optimized for device manufacturability. A propagation loss of about 0.8cm$^{-1}$ allowed a laser cavity length of 5 mm. Lateral optical confinement was provided by a 130um-wide ridge waveguide. A proprietary passivation technology was used together with an uninjected current region of 300um to further increase the catastrophic optical mirror damage (COMD) threshold and enable reliable operation at operating conditions. Low reflective mirror coatings of about 2% were deposited by electron gun technique on both front and back laser facets.
A 500um-long Distributed Bragg Reflector (DBR) was integrated on the rear side of the device, providing a reflectivity of about 90%, at a wavelength defined by the grating pitch. Figure 1 shows a schematic of the laser diode and Figure 2 shows SEM pictures of the DBR cross sections.

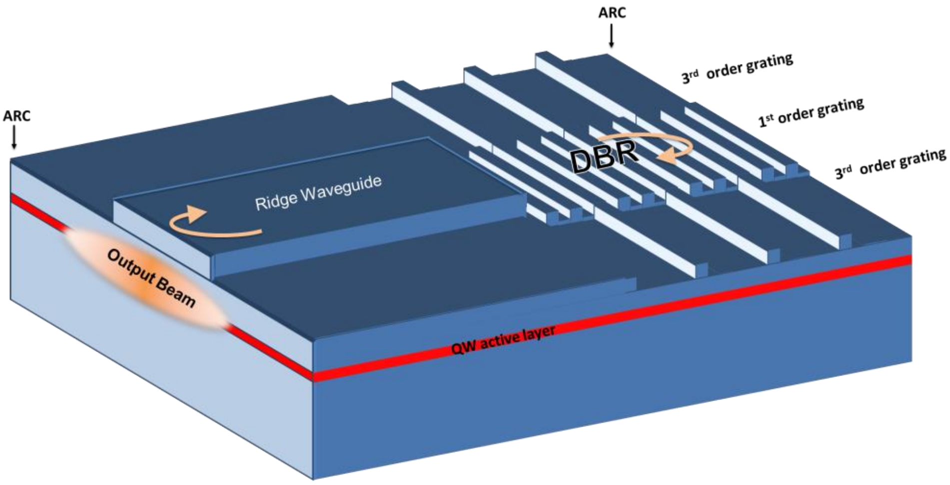


Figure 1: Schematic of the DBR high power laser diode

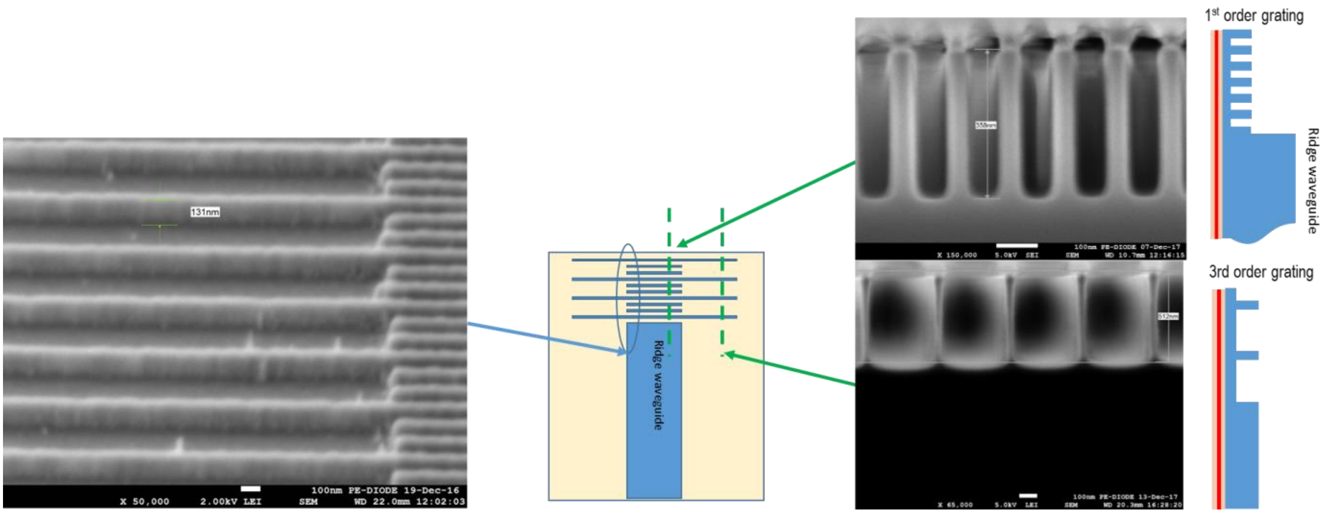


Figure 2: (*center*) schematic drawing of Bragg grating; (*left*) SEM top view of multiple order grating (*right*) SEM cross sections of first order and third order gratings

A shaped DBR, 1st order grating in the central region and 3rd order grating in the lateral regions (see Figure 2) significantly simplified the deep-etching technological process, needed to achieve high reflectivity, while allowing a tailoring of the lateral optical confinement. The lateral confinement is indeed provided by the effective index differences between 1st order and 3rd order grating regions (patent pending). Excellent shape and aspect ratio have been demonstrated by properly optimized Electron Beam Lithography writing and Reactive Ion Etching process development.

Figure 3 shows a calculation result of the spectral reflectivity of the DBR section and a fabrication tolerance analysis as a function of grating shape parameters. Despite the apparently critic time control of the grating etching, the wide process window allowed by this design resulted in a high fabrication yield.

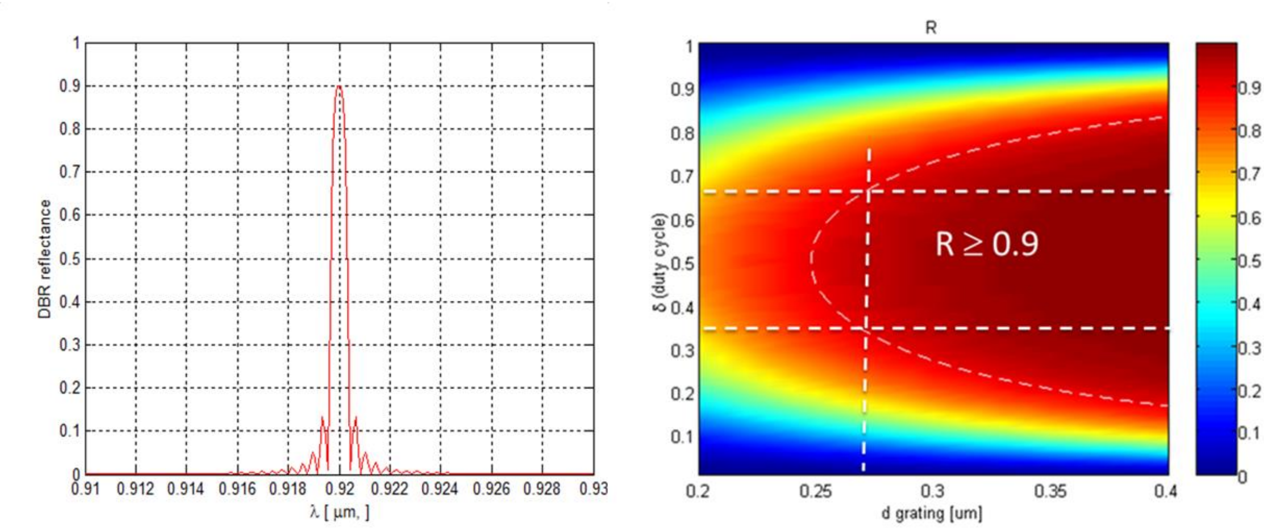


Figure 3: Calculation of the spectral reflectivity of the DBR section *(left)* and maximum of the reflectivity versus grating shape parameters: duty cycle δ,and pitch d (*right*)

Conventional technology for the DBR section, which needs to be transparent at the wavelength emission of the laser diode, is using a higher-energy-gap material: butt-coupling or quantum-well intermixing techniques are the most widely used technology approaches. However, avoiding epitaxial regrowth in a high power laser diode is of utmost importance for the reduction of defects within the cavity, extremely critical for high power laser diodes. Moreover, both techniques would imply a significant manufacturing cost increase. Due to the high optical power density within the laser cavity, none of the above techniques were required in our device: indeed, as demonstrated by a modelling based on the nonlinear-coupled-mode equations (see Figure 4) the DBR section is effectively switched to transparency by the optical beam itself. The insertion loss penalty due by the residual absorption in the DBR section produces negligible effect, in the very few percent range, on the laser threshold and the slope efficiency. The simple manufacturing process significantly overcomes this small penalty, which anyway doesn't prevent to reach the optical power target.

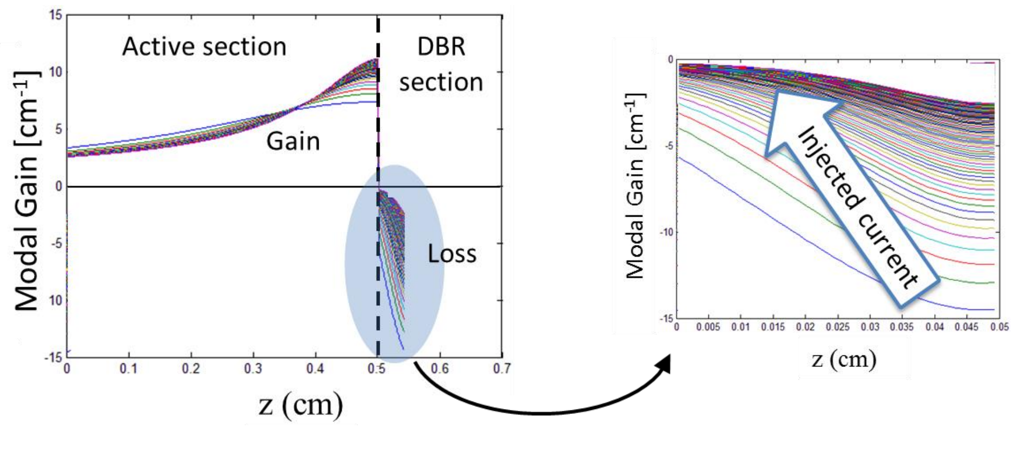


Figure 4: Calculation of the induced transparency in the DBR section

## 3. EXPERIMENTAL RESULTS

HPDL-DBR technology was demonstrated on 4” wafer, integrating three different pitches. Laser devices have been tested at bar level (pulsed conditions) to derive wafer statistics and verify electro-optical performances across the wafer and for different wavelengths. A set of single DBR-HPDLs have been also assembled p-side down on ceramic carriers (by Gold - Tin hard soldering die attach), obtaining the so-called Chip on Carrier (CoC), necessary for CW tests at high bias – high power conditions.
Measurements performed in CW, 25 °C on CoC demonstrated (Figure 5) power in excess of 14 W. power gain respect to the previous realization (reported in [4]) is also due to the optimized grating writing – etching technology, reducing therefore losses and improving grating reflectivity.
Moreover, thanks to the accurate epitaxial structure design and fabrication technology, measurements show also very low diode voltage (1.5V at 20A), effective in achieving low power dissipation, decreasing the active junction temperature operation and contributing to long term reliability at operating conditions.

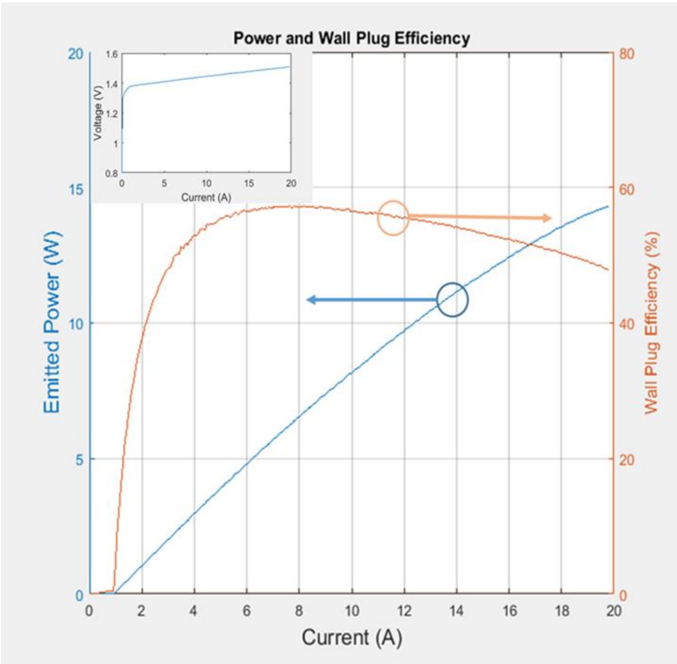


Figure 5: Emitted power and conversion efficiency (and diode voltage, inset) versus injected current (25 °C)

High purity emitted spectrum and excellent stability over current are key requirements for a wavelength stabilized high power diodes. Figure 6 shows results of emitted spectrum stability versus bias current in the range of 2 to 14 A: standard Broad Area Fabry Perot laser usually shows more than 10 nm of spectrum occupation, whilst DBR-HPDL has demonstrated a reduced wavelength shift of less than 2 nm, in the same bias range.
As described, narrow spectrum of a DBR-HPDL enable possibility of multiple emitted wavelength from the same wafer, by writing multiple pitches on the wafer itself. Results of devices achieved by writing three different pitches on the same wafers are reported in Figure 8: three emitted wavelengths, 2.5 nm spaced have been obtained from the same wafer, with similar characteristics of emitted power and spectral width.

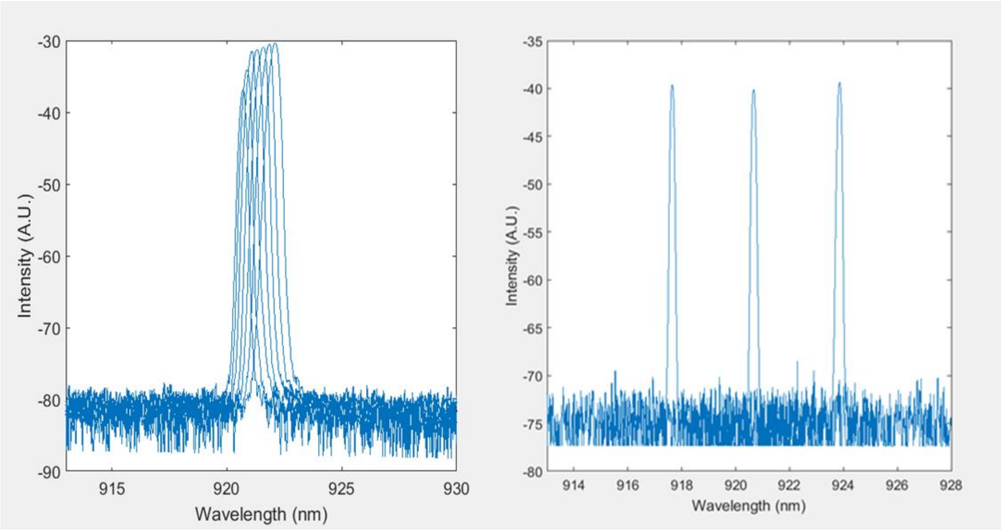


Figure 6: *(left)* emitted spectrum at 25 °C, 2-15A bias; *(right)* three wavelengths, 2.5 nm spaced emitted from the same wafer

Uniformity of device performances have been investigated: goal was to analyze variability of grating technology across the wafer, demonstrating uniformity of performances at different wavelengths.

Figure 7 shows statistical distribution of threshold current and external efficiency versus wavelengths (pulsed conditions, measured at bar level). Box Plots are showing 25-75 % population for the three different pitches: very limited trend of threshold can be identified, mainly due to the different gain peak – Bragg wavelength detuning, and consequent slightly different threshold gain conditions. More important, devices shown same efficiency (close to 1 W/A) for the three different wavelengths.

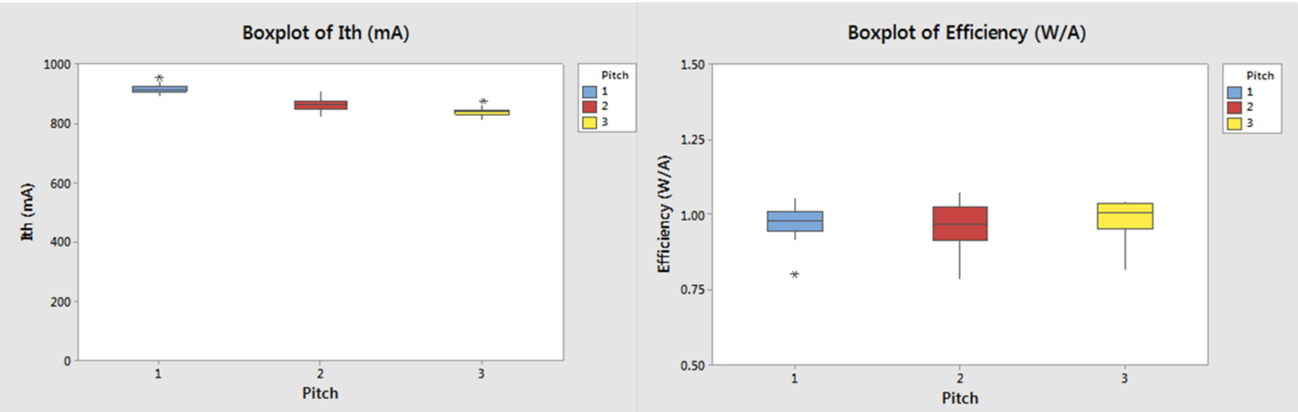


Figure 7: *(left)* box plot statistics of threshold current and *(right)* conversion efficiency (W/A)

Having analyzed the key parameters statistics, and defining possible specs - and therefore production test limits – for a typical high power laser diode application, was possible to study the process capability and test the maturity of the technology versus the manufacturability requirements. Preliminary study was based on the conversion efficiency, as the key performance indicator. Figure 8 shows overall distribution and capability analysis for the efficiency parameter: an observed yield of 98% was demonstrated, for a hypothetical lower production test limit (LSL) of 0.8 W/A. More accurate capability analysis will imply a precise definition of the product specifications based on the power required for the specific application; however, the tight distribution is for sure a promising indicator of the maturity of the present technology.

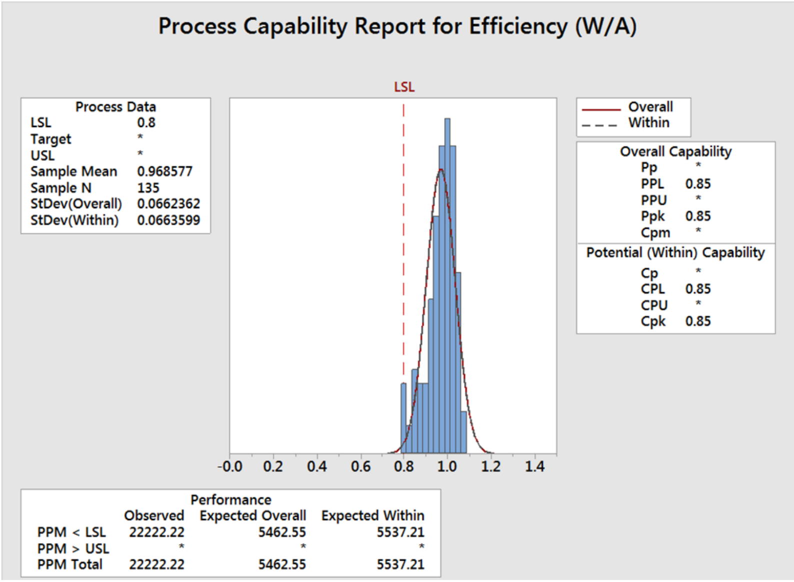


Figure 8: capability analysis for overall process efficiency, showing 98% observed yield

## 4. CONCLUSIONS

DBR High Power Diode Laser (DBR-HPDL), exploiting multiple-orders Electron Beam Lithography (EBL) optical confining grating have been demonstrated, emitting up to 14W in the 920nm range and demonstrating high spectral purity and wavelength stability versus injected current. EBL grating technology enable multi-wavelength array of diode laser simply by varying grating pitches along the wafer: present paper demonstrates DBR-HPDLs 2.5 nm spaced, with similar electro-optical characteristics. Performance uniformity across the 4” wafer, as well as across the different grating pitches, is a key indicator of a manufacturable and reliable technology, candidates DBR-HPDL as a suitable device for wavelength stabilized pump source and high brightness applications exploiting Wavelength Division Multiplexing

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