High-power 1.5µm laser diodes for LIDAR applications

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***Abstract*— We report on the development of high peak power laser diodes emitting in the 1.5 µm wavelength band for eye-safe LIDAR applications. Different techniques for wavelength locking to and operation with a narrow emission spectrum are discussed. Furthermore, we review the strategies to increase the beam brightness. Recent progress in new epitaxial layer designs enabling high peak powers is also discussed. Finally, we discuss the performance of the laser diodes in terms of improvements they render possible for high-performance LIDAR systems.**

***Index Terms*—Bulk gain region, DBR-laser, Eye safe laser, Gain Switching, LIDAR, Tapered laser, high brashness laser.**

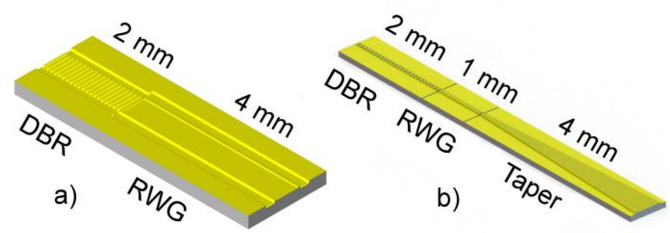

Fig. 1. Laser diode layouts studied: (a) Broad area wavelength stabilized laser with un-pupped DBR section and RWG section. (b) Tapered DBR laser containing single mode waveguide section between un-pumped DBR section and tapered section.

I. INTRODUCTION

CURRENT automotive LIDAR systems mainly work in the wavelength range from 800 nm to 940 nm. The maximum emission power in this wavelength range is limited by the requirement for eye-safety. The power limitation becomes a major issue in particular when operating in adverse weather conditions when the detection range decreases dramatically because the light is attenuated and scattered by raindrops or fog [1]. Considerably higher optical powers can be used in the wavelength range around 1550 nm, which is currently employed e.g. in military applications [2]. However, these systems usually utilize fiber lasers or amplifiers and are too bulky and expensive for many applications [3]. An additional benefit of the 1.55 µm wavelength range is that the absorption due to atmospheric moisture is very low. On the other hand, low absorption windows around 1.55 µm leads to increased sensitivity to solar radiation causing higher background noise. The signal-to-noise ratio of such systems can be improved by using temperature-stable lasers with a narrow emission spectrum in connection with pass-band filters to reject the broad solar radiation and reduce the background noise.

II. MONOLITHIC WAVELENGTH LOCKING

To meet the requirement for narrow bandwidth, temperature stable emission we have developed high peak power broad-area laser diodes emitting in the 1.5 µm wavelength. We employ two design architecture, shown in Fig. 1, both containing a monolithically integrated surface grating section for wavelength stabilization and a ridge waveguide (RWG) section for gain. We benchmark the performance merits of the wavelength stabilized laser against traditional Fabry-Pérot (FP) diodes fabricated within the same processing batch and having an identical epitaxial design. The monolithic DBR grating provides an effective way to wavelength lock the 1.5 µm diode laser without a significant penalty to the output power. Compared to the dominant method to stabilize multimode lasers with external volume Bragg gratings (VBGs), the fabrication of the monolithic grating using nanoimprint lithography is more cost-effective and enables parallel fabrication on the wafer level. Moreover, monolithic gratings do not impose additional costly assembly and alignment steps.

III. TAPERED LASER DESIGN

Tapered high-power lasers enable a high beam quality than broad-area lasers while still exhibiting a relatively high output power. This geometry enables the expansion of the mode volume and the cross section of the

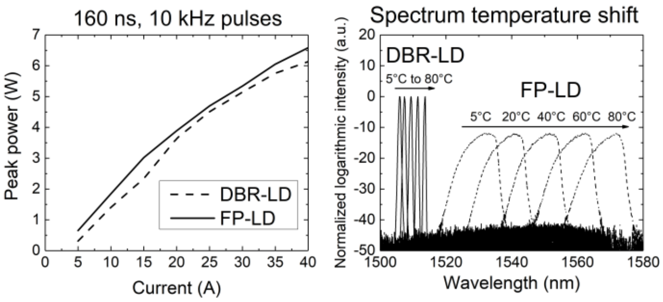

Fig. 2. Comparison between broad area FP-LD and Broad area DBR-LD show comparable output power characteristics but a device with DBR-locked spectrum exhibits much narrower spectrum that drifts five times less with temperature. Lasers contain a 4 mm long and 180 µm wide broad area RWG section and (optionally) a 2 mm long DBR section. The epitaxial design is based on three quantum wells in a symmetric waveguide. [4]

beam at the emission facet thus allowing high power and a reduced power density at the facet. At the same time the output beam can be focused tightly or even coupled back to a single more waveguide [5]. Our research towards nanosecond pulsed high peak power tapered lasers aims to develop a high-brightness source that allows the use of cost effective low-noise small-aperture detectors and enables high lateral resolution LIDARs. To this end, we recently demonstrated the operation of wavelength locked tapered diode lasers delivery close to 5W peak-power ns-pulses (see Figure 3).

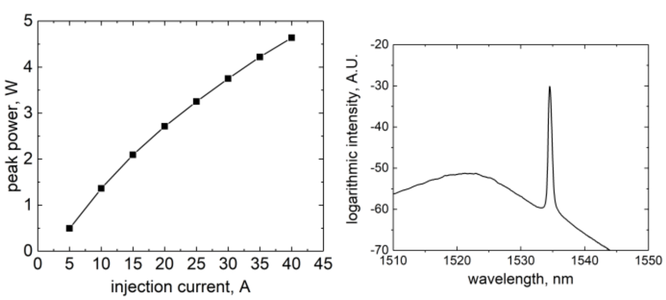

Fig. 3. Output power characteristics and spectral characteristics of a tapered DBR laser driven with 200 mA DC bias to waveguide section and from 5 A to 40 A 160 ns pulsed current to the tapered section. The laser contains a 4 mm long tapered section, a 1 mm long single mode waveguide section, and a 2 mm long DBR grating section. The active region contains 4 quantum wells. [6]

IV. WAVEGUIDE STRUCTURE FOR HIGH POWER

The development of high-efficiency, high peak power 1.5 µm lasers is enabled by comprehensive analysis of the internal losses in a laser operated under different power levels. Recent analysis [7] suggests that a strongly asymmetric waveguide design with the active layer near the *p*-cladding is beneficial to suppress strong p-side intervalance band absorption and to avoid current induced carrier accumulation in the optical confinement layer. Moreover, optimization of both *p*- and *n*-side doping can be used to minimize both free carrier absorption and two-photon absorption effects. Such layer design has been recently demonstrated experimentally with favorable high-power characteristics shown in Fig. 4.

In conclusions, we expect that the proposed technology will contribute to the development of eye-safe LIDAR systems by improving their performance especially under bright daylight illumination.

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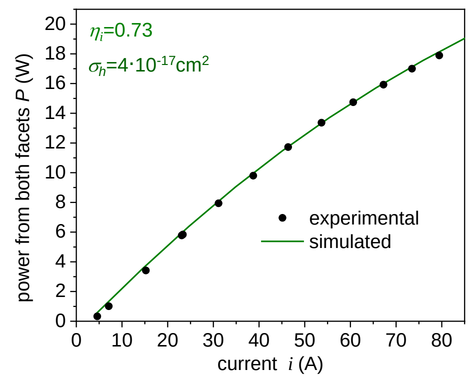

Fig. 4. Output power characteristics of 1.5 µm broad area FP laser with 90 µm wide emission stripe and 2 mm long as-cleaved cavity. The epitaxial design is based on a strongly asymmetric design with a bulk gain region. The pulse length is approx. 60 ns. [8]

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