

Wide Temperature (-20°C – 95°C) Operation of an Uncooled 2.5-Gb/s 1300-nm DFB Laser

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Abstract—This letter describes a 2.5-Gb/s 1300-nm distributed-feedback laser that can operate in a wide temperature range of -20°C to 95°C . We present RF and dc characteristics of the device and the statistical distribution of threshold current and slope efficiency at high temperature. Finally, we demonstrate the device performance in a 2.5-Gb/s small-form-factor module up to 85°C .

Index Terms—Modulation, optical transmitters, semiconductor heterojunctions, semiconductor lasers, temperature.

I. INTRODUCTION

LOW-COST uncooled fiber-optic transceiver modules have enabled explosive growth in the use of fiber-optics technology in both enterprise and public networks. Future trends require modules to work at higher temperatures (85°C), at higher bit rates (2.5 Gb/s), with lower supply voltages (3.3 V) and have small-form-factor (SFF) dimensions for higher port density. Uncooled distributed-feedback (DFB) lasers, which are required for intermediate (15 km) and long (40 km) reach applications, have shown high speed operation up to 85°C [1]–[3]. Crucially, this is insufficient to achieve good high-temperature performance in an uncooled transceiver module at 85°C due to the presence of self-heating from packaging and the laser driver, especially at high bit rates. It is estimated that to achieve 85°C ambient module temperature operation, the optical subassembly (laser on a header with a ball lens attached) must work to temperatures up to 95°C .

In this letter, we present the first 1300-nm DFB which can work in the wide temperature range from -20°C to 95°C . This level of performance, particularly at high temperature, is used to realize very wide temperature (-20°C and 85°C) operation of uncooled transceiver modules at speeds up to 2.5 Gb/s.

II. DEVICE DESIGN

To achieve the high temperature and high-speed performance in a DFB laser, several factors must be addressed.

Firstly, the optical bandwidth must exceed the data rate at the limits of coupled power and available drive current in the application over all temperatures. To achieve this, we have adopted a laser active region containing nine compressively strained InGaAsP quantum wells and unstrained barriers with a bandgap around $1.1\ \mu\text{m}$. The large well number ensures a high differential gain, and hence, large resonance frequency

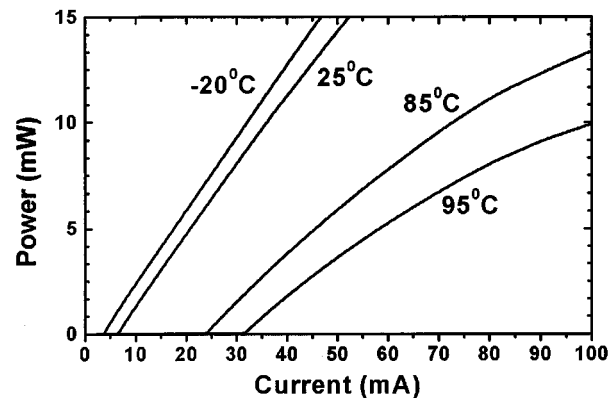


Fig. 1. Light-current (L - I) characteristics of the DFB laser.

and bandwidth [4]. We maintain the resonance frequency over temperature, an optimized P-N-P-N buried heterostructure (BH) structure has also been developed.

Secondly, the electrical parasitics must be minimized. A low capacitance structure is realized using isolation trenches, patterned p-side metal and dielectric layers [5]. A low series resistance of around $5\ \Omega$ also minimizes the parasitics.

Finally, to achieve single mode operation, a conventional index coupled DFB grating is defined in the structure. A κL value of 1.5 is used since it gives flat optical densities through the cavity [6] which reduces spatial hole burning (SHB). SHB can be the dominant effect in reducing the single-mode yield [7]. To maintain single DFB mode performance over temperature, a low reflectivity AR coating is deposited on one end of the device to suppress Fabry-Pérot (FP) lasing modes. A high reflectivity HR coating is deposited on the other facet. For high speed, the DFB lasing wavelength should be shifted to as short a wavelength with respect to the gain peak as possible for high differential gain [4]. In our device, the DFB mode is positioned at around 5–10 nm to the short wavelength side of the gain peak at room temperature. However, the device operates still further from the gain peak at elevated temperatures. This increases the demands on the blocking layers which, eventually, leads to degradation in performance. Consequently, the quality of the blocking structure is an important factor in achieving high-speed performance at very high temperatures.

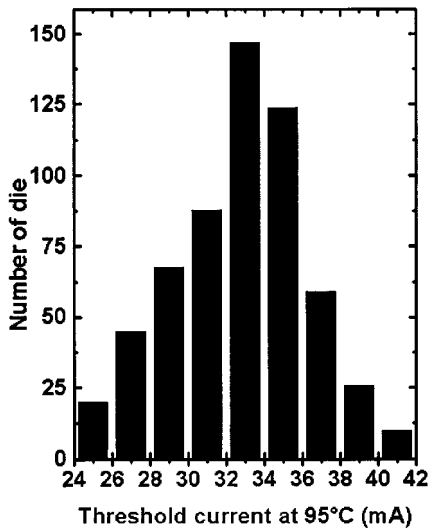
III. DC CHARACTERISTICS

Laser devices have been assembled into full optical sub-assemblies (OSA) consisting of a mini (3.8 mm) CD header, ball lens and fiber receptacle. Fig. 1 shows an example of the light versus current (L - I) characteristics of the DFB laser.

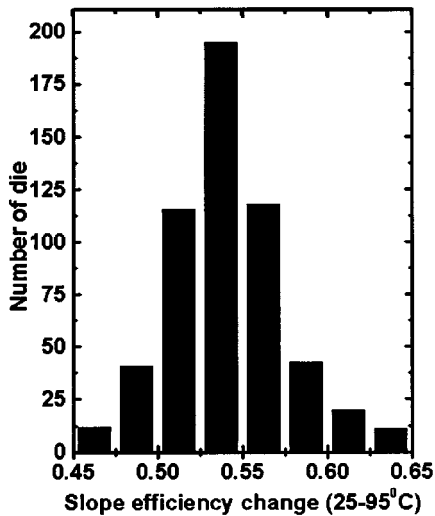
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(a)



(b)

Fig. 2. Distributions of (a) threshold current (95 °C) and (b) slope efficiency change (25 °C–95 °C) measured from optical subassemblies.

At 25 °C, typical threshold currents were around 7 mA and exfacet slope efficiencies of 0.4 mW/mA. In the application, the device operates in an elevated temperature environment due to module self heating. At a module temperature of 85 °C, the OSA is estimated to be operating at temperatures up to 95 °C. As can be seen in Fig. 1, both low threshold current (I_{th}) and high slope efficiencies (η) are maintained at 95 °C.

To assess the variation in performance at high temperature, lasers from eight wafers were fully characterized. Fig. 2 shows the distribution of (a) threshold current at 95 °C and (b) slope efficiency ratio, $\eta(95\text{ °C})/\eta(25\text{ °C})$. It was found that at 95 °C: $I_{th} = 32\text{ mA} \pm 6\text{ mA}$ and the slope efficiency ratio was 0.53 ± 0.09 . This shows that good high-temperature performance is achieved from wafer to wafer.

IV. DEVICE RF PERFORMANCE

Fig. 3 shows the optical small-signal response from the laser. Devices are bonded down onto AIN substrates and measured

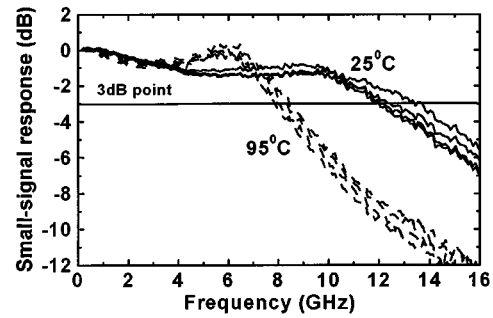


Fig. 3. Small signal response measured at $I_{th} + 50\text{ mA}$ at 25 °C and 95 °C.

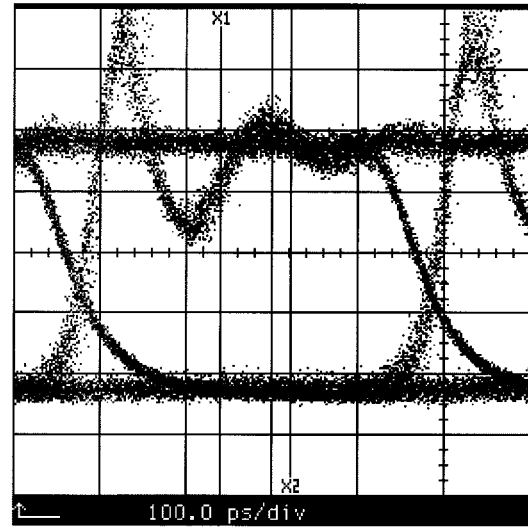


Fig. 4. Unfiltered eye diagram at 2.5 Gb/s at 95 °C.

using an Agilent 8703A lightwave component analyzer and a high-speed probe. The initial slope in the small signal response can be attributed to the electrical parasitics of the device and leads to a RC parasitic time constant of 32 ps. This corresponds to an estimated chip capacitance of 6.5 pF using the measured series resistance of 5 Ω . The low parasitics allow optical 3-dB bandwidths of greater than 10 GHz at $I_{th} + 50\text{ mA}$ at 25 °C. At high temperature, the drop in slope efficiency reduces the resonance frequency at fixed current above threshold. Optical 3-dB bandwidths greater than 7.5 GHz at 95 °C are achieved at $I_{th} + 50\text{ mA}$ under the continuous-wave conditions of the measurement.

To simulate the device performance under modulation, the 2.5-Gb/s eye diagram has been measured at 95 °C using an Agilent 71 612 BERT [nonreturn-to-zero (NRZ) $2^{23} - 1$ pseudorandom binary sequence (PRBS)] and a digital communications analyzer (DCA) with an Agilent 83485B optical receiver. The devices was bonded down onto an AIN tile and signal applied using a 45- Ω loaded high-speed probe. The device was set up with a mean bias current of $I_{th} + 25\text{ mA}$, where I_{th} was 32 mA and the voltage swing was set to give an extinction ratio of 10 dB. Light is collected from the laser facet using a lensed fiber. The mean exfacet power, at $I_{th} + 25\text{ mA}$, is estimated to be 5 mW at 95 °C. The unfiltered eye at 95 °C is shown in Fig. 4. The resonance frequency, estimated from the oscillations in the logic one level, is around 6 GHz. This would correspond to a

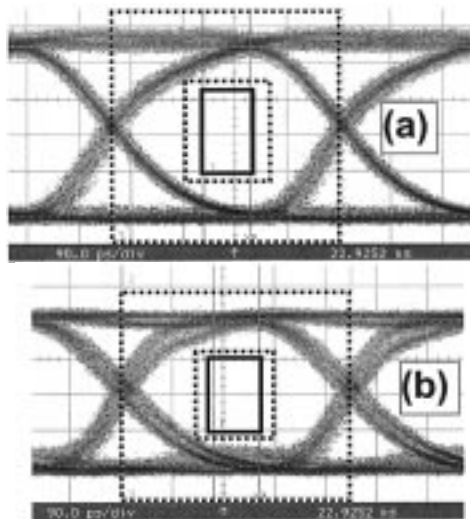


Fig. 5. 2.5-Gb/s eye diagrams from SFF modules using the DFB laser measured at oven temperatures of (a) -20°C and (b) 85°C .

bandwidth of greater than 10 GHz at $I_{\text{th}} + 50$ mA under modulation conditions. Work continues on this structure to realize 10-Gb/s operation at high temperature for the next generation of Ethernet applications [8].

V. MODULE PERFORMANCE

Devices were built into SFF transceiver modules with an LC style connector which require only a 3.3-V supply.¹ The eye diagrams at 2.5 Gb/s were taken with a NRZ $2^{23} - 1$ PRBS pattern using an Agilent 70841B pattern generator. An OC48 rectangular eye mask was aligned to the center of the filtered eye. The module was tested under conditions for intermediate reach (15 km) applications, namely, a mean power into fiber of -2.5 dBm and an extinction ratio of between 10–12 dB. The module was tested over temperature in a convection oven from -20°C to 85°C . The mean power and extinction ratio over tem-

¹Details on the LC small form-factor transceiver family can be found at www.agilent.com and search for HFCT-5942 or “SFF.”

perature were maintained by the controller circuit in the module. Measurements were taken after as settling time of tens of minutes to ensure the module had reached the desired temperature. Fig. 5 shows typical eye diagrams at (a) -20°C and (b) 85°C . At 25°C , eye margins of excess of 19%. At 85°C oven temperature (95°C OSA temperature), the eye margin was 18%.

VI. CONCLUSION

We have developed a 1300-nm DFB laser which can operate at 2.5 Gb/s in a wide temperature range of -20°C to 95°C . This very wide temperature performance has enabled the demonstration of SFF transceiver modules that operate at 2.5 Gb/s, uncooled, from -20°C to 85°C .

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