Fabry–Pérot lasers promise low-cost 10 Gb/s Ethernet

With 10 Gb/s Ethernet port shipments rising fast following two quiet years, the opportunity now exists for increasingly reliable, affordable Fabry–Pérot lasers to replace more complex designs. Modulight's Pekko Sipilä reports.

The two hot topics driving today's short-reach 10 Gb/s optical networks are cost and standardization. Expansion of this sector has been inhibited through high-price modules containing expensive components such as distributed feedback (DFB) lasers and electro-absorption modulated lasers (EMLs). One solution is to use relatively low-priced Fabry–Pérot (FP) lasers that are manufactured by a higher yield process not requiring equipment-intensive gratings and overgrowth steps.

Further savings arise through the omission of ancillary components. For example, expensive optical isolators – which are required to eliminate the influence of back reflections in reflection-sensitive DFB lasers – are not necessary for reflection-tolerant FP lasers.

Although DFB lasers offer better spectral purity and single longitudinal-mode operation, they do so at an unbearably high price for enterprise applications. With the vast majority of transmission distances being less than 300 m, high-quality transmission can be obtained using multiple longitudinal-mode FP lasers, provided that a narrow spectral width is maintained during their manufacture.

Arrested development

A lack of suitable standards has hampered the development of FP lasers for short-range networks. In 1999, serial 10 Gb/s Ethernet interfaces using uncooled, unisolated FP lasers were promoted by many manufacturers. However, the physical media-dependent (PMD) sublayer was omitted from the IEEE 802.3ae standard, partly because the number of PMD options was simply getting too large.

In the intervening years, a greater up-take of 10 Gb/s Ethernet has increased pressure to set an IEEE standard for low-cost sources. Today the recently formed IEEE 802.3aq study group is considering the multimode fiber solution 10GBASE-LRM, which utilizes Electronic Dispersion Compensation. In this application, FP lasers can deliver significant component cost reduction. Investigating this benchmark, engineers from Infineon Technologies noted that connector offset introduced loss and, consequently, a relatively large power penalty, but FP laser performance was superior to that of both DFB lasers and EMLs.

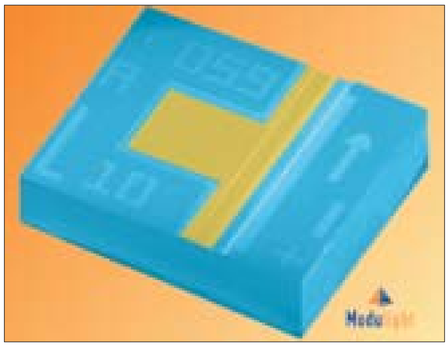

Fig.1. This micrograph shows Modulight's 1310 nm 10 Gb/s Fabry–Pérot laser die.

Table 1

Parameter	*Median at 25 °C*	*Median at 85 °C*
Ith (mA)	12.69	24.38
Slope (mW/mA)	0.32	0.25
Rs (Ω)	4.67	3.99
λ (nm)	1297.53	-
Δλ (nm)	0.85	-
Vertical FWHM (°)	34.20	-
Horizontal FWHM (°)	23.70	-

Median values of static parameters for Fabry–Pérot lasers in accelerated life tests.

Modulight's 1310 nm 10 Gb/s FP laser chips were released in January 2003, and have been shipped to a number of customers. The lasers are based on the AlGaInAs material system, which, historically, has been associated with poor reliability due to the presence of aluminum (which readily oxidizes). However, AlGaInAs-based laser reliability has improved substantially over the years and this system is used today in many 10 Gb/s lasers. Indeed, reliability tests of Modulight's lasers suggest lifetimes of hundreds of years.

Modulight's FP lasers are fabricated in-house using an all-solid-source MBE reactor, which provides good control of the growth of the quantum wells and barriers that form the active region. The laser structure – grown on exactly cut, n-type InP substrates – contains an active region with multiple compressively strained (~1.4%) AlGaInAs quantum wells, which are tuned for laser emission at around 1310 nm. The quantum well layers have a thickness of 5 nm and are separated by lattice-matched, 10 nm thick AlGaInAs barriers. This optically active region is surrounded by AlGaInAs (with a bandgap of 1.35 eV) and AlInAs/InP layers to form a typical wave-guiding structure for a semiconductor laser.

Industry-standard device-processing steps enabled the fabrication of ridge waveguide FP lasers with ridge widths of 2.5 µm, 250 µm cavity lengths, and high-reflection and anti-reflection facet coatings of 70 and 30%, respectively. A higher back-facet reflectivity would suppress the threshold current, but also reduce the signal from the standard monitor photodiode that is used to maintain constant laser output during operation.

Low-cost 10 Gb/s transceivers in XENPAK, X2 and XFP packages do not use active cooling for the laser, and so stable behavior as a function of case temperature is essential for the laser dies. Lasers emitting at 1310 and 1550 nm are traditionally made from the InGaAsP–InP material system. However, InGaAsP-based lasers offer poor performance at high temperature. AlGaInAs–InP lasers [1] have been developed to overcome these high-temperature-related problems and they replace InGaAsP-based lasers in applications where uncooled operation is required over wide temperature ranges, including up to 85 °C.

The light–current behavior was studied for a set of Modulight 10 Gb/s FP lasers operated with 25 and 85 °C case temperatures in continuous-wave mode. Linearity of the power output is very good even at 85 °C – at this temperature InGaAsP-based lasers already show a significant power drop due to saturation of the slope efficiency. For our lasers, slope efficiency as a function of temperature is fairly constant. The median threshold current for the device is 12.97 and 25.41 mA at case temperatures of 25 and 85 °C, respectively.

Control is key

An important factor that limits transmission distance is chromatic dispersion. Early suggestions for FP laser-based 10 Gb/s PMDs for 2 km transmission assumed a maximum root-mean-square (RMS) spectral width of 2–2.5 nm. This requires a high degree of control throughout the entire manufacturing process, from wafer growth to test and measurement. The spectral properties of Modulight's lasers are measured with an optical spectrum analyzer, and spectral RMS values are calculated assuming a noise level of –20 dB. Figure 2 shows the distribution of the RMS spectral width for a population of Modulight's 10 Gb/s FP lasers operating at 5 mW at two case temperatures. A typical value for the spectral width is 0.9 nm for a 25 °C case temperature; the spectral width remains well below 2 nm even at a 85 °C case temperature.

The frequency response of the laser chips was measured using a microwave probe and a network analyzer. The resonance frequency, which determines the maximum modulation speed of the device, was 13 GHz at 25 °C and 11.6 GHz at 85 °C with a bias level of Ith + 66 mA. The change in resonance frequency over 60 °C is only 11%, which is small compared with traditional InGaAsP lasers and AlGaInAs lasers [2].

The long-term reliability of Modulight's 10 Gb/s, 1310 nm FP lasers has been studied by extended accelerated ageing tests in accordance with Telcordia guidelines. The study involves characterizing bare die laser chips at 25 and 85 °C prior to bonding on submounts. Before starting the time-consuming ageing test, devices were screened from standard production lots using a 24 hour burn-in test, conducted at 80 mA constant current and 100 °C.

A burn-in induced change of more than –5 or 1% in threshold current, or –2 or 5% change in slope efficiency in output power versus current measurements at 25 °C led to rejection.

Eleven devices meeting these criteria underwent an accelerated lifetime test, with conditions of 10 mW constant output power at 85 °C. Chip-level static parameters for these lasers are summarized in table 1. These

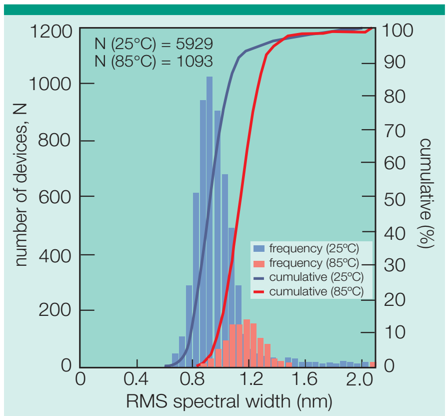

Fig. 2. More than 90% of Modulight's lasers have an RMS spectral width of less than 1.3 nm at 85 °C, which is well inside the 2–2.5 nm required for 2 km transmission.

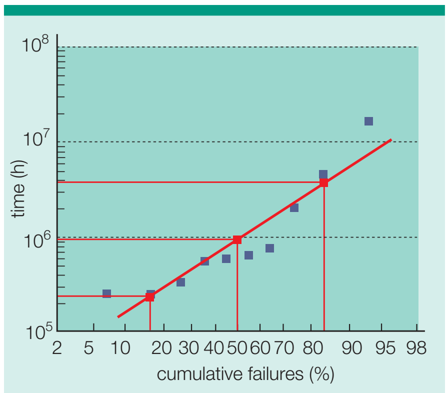

Fig. 3. The median lifetime of a Modulight laser is calculated to be 9 × 10^5 hours.

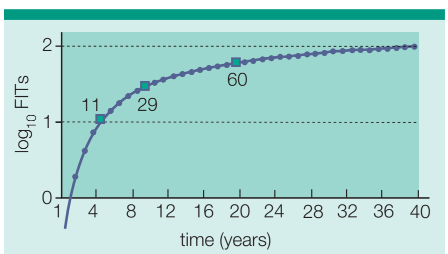

Fig. 4. These FIT values show that the lasers are reliable enough for telecom applications.

figures are typical of the several thousands of lasers fabricated by Modulight using the same process. More than 130,000 device hours have been collected and analyzed to evaluate laser reliability.

For the laser analysis we defined end-of-life (EOL) as the time taken for the threshold current to increase by 50% from its initial value. The time to failure for each device can then be calculated by assuming that the EOL can be extrapolated linearly as a function of time. Calculations were performed on 10 lasers – the remaining laser showed no clear degradation trend during the lifetime test, indicating an infinite lifetime.

The analysis also assumed that only one wear-out failure mode exists and that laser lifetime follows a lognormal distribution. The lifetime data of the lasers at 85 °C, alongside the line of best fit, is presented in figure 3. The median lifetime – the point where the fitted line intercepts the 50% point – is equal to 9.38×10^5 hours (107 years). The median lifetime at other temperatures can be calculated if the activation energy – the energy associated with a particular failure mode – is known.

Using Telcordia default activation energies of 0.4 eV for wear-out failure and 0.35 eV for random failures, at 25 and 40 °C median lifetimes are 1.27×10^7 hours (1450 years) and 6.04×10^6 hours (689 years), respectively.

Lasers with longevity

To the best of our knowledge, only a few reports exist regarding the reliability of AlGaInAs-based transmitter lasers operating at 1310 nm [1, 3]. In reference 1, mean-time-to-failure, or median life, is estimated at 82000 hours (9.4 years) at 85 °C, which is significantly less than that predicted for our lasers. Work carried out by Takaguchi *et al*. [3] only indicates that no failures have been observed after 3400 hours of operation.

Wear-out failure rates at 40 °C after 5, 10 and 20 years of service can be calculated using the same lognormal model. A FIT value of 11 – that is 11 failures per billion device hours – is calculated for lasers with 5 years of service (see figure 4). Corresponding FIT values after 10 and 20 years are 29 and 60, respectively. These FIT numbers show that the lasers have sufficient long-term reliability for use in telecom equipment, where the industry-standard requirement is a FIT value of less than 200 for 20 years' design life. The reliability, allied with the attractive price of FP lasers, makes these devices competitive in short-haul 10 Gb/s communications, particularly if standardization work proceeds successfully.

Further reading

[1] C-E Zah *et al*. 1994 *IEEE J. Quantum Electron*. **30** 511–523.

[2] T Ishikawa *et al*. 1998 *IEEE Photonics Technology Letters* **10** 1703–1705.

[3] T Takaguchi *et al*. 2000 *ECOC Proceedings* **26** 1.

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