Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 58-59

Invited

VCSEL and Its Applications for Optical Interconnection and Switch

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1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) are promising devices for the optical data links required for achieving large capacity switching systems and massively parallel computers. It is potentially a low-cost laser because it enables on-wafer mirror growth, on-wafer processing, on-wafer testing and on-wafer screening, all of which result in high yields and high reliability. Also, the package configuration can be basically the same as that of a detector, and the low-divergent circular beam allows effective fiber coupling.

The overall performance of the VCSEL itself has recently been improved significantly. Low threshold current (below 10 μA) [1], high wall-plug efficiency (over 50%) [2], high-speed modulation (10 Gbps) [3], and complete polarization control [4] have been reported. Several modules for parallel data links have been reported using one-dimensional (1-D) VCSEL array [5]-[7].

In this paper, a two-dimensional (2-D) VCSEL module developed to take full advantage of VCSELs is presented [8]. Applications in parallel transmission and a space-division switch are also presented.

2. VCSEL

The typical structure of our VCSEL-array chip is schematically shown in Fig. 1. Each VCSEL has a 10-μm index-guiding mesa to achieve a transverse multimode for fine coupling to a multimode fiber, and it emits laser light at a wavelength of around 980 nm from the antireflection-coated bottom surface of the GaAs substrate [9-11]. The typical threshold current and quantum efficiency of the VCSEL are 1.5 mA and 0.29 W/A, and the 3-dB modulation bandwidth is 7.0 GHz [12]. For the module, it was arranged 8-by-2 with a pitch of 250 μm and 500 μm respectively for the horizontal and vertical directions.

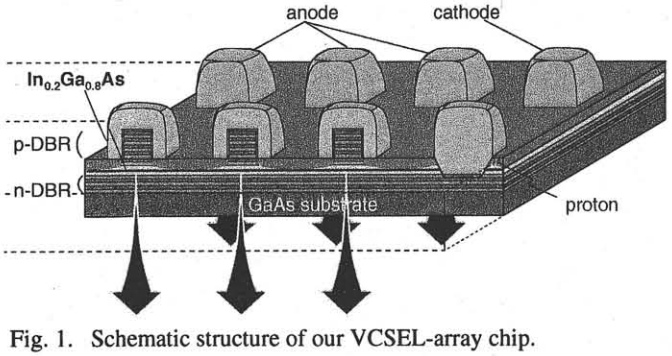

Fig. 1. Schematic structure of our VCSEL-array chip.

3. Multidimensional VCSEL-Array Module

The VCSEL-array module is based on the following four major concepts: 1) 2-D transmission with a structure compatible for a 1-D module. 2) completely alignment-free packaging using a self-alignment technique. 3) direct push/pull connection to a standard MPO-compatible fiber connector. 4) mass-producible plastic molding for all the components. The schematic structure is shown in Fig. 2 [8].

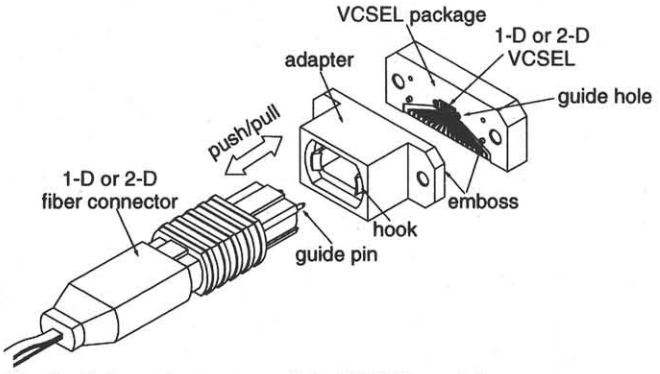

Fig. 2. Schematic structure of the VCSEL module.

The mounting configuration of the VCSEL module is shown in Fig. 3. The VCSEL-array chip is first mounted on the Si substrate by using the self-alignment flip-chip solder-bonding technique, and the substrate is then mounted on the plastic package by using a self-alignment mounting process which we call ball-guide die bonding [13].

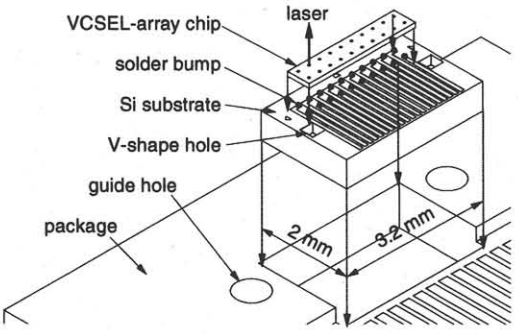

Fig. 3. Mounting configuration of the VCSEL module.

The module exhibits an optical coupling loss of 0.67 ± 0.23 dB (efficiency: 85.8 ± 2.93%) and a loss deviation of less than 0.26 dB for 100 matings with the fiber connector. The modules were operated at a bit rate of 1 Gbps/ch without an isolator and showed floorless BER performance

at temperatures up to 70°C. At 1 Gbps/ch their optical sensitivity at a BER of 10^{-11} was -26.0 dBm ± 0.9 dB. The overall performance of the 2-D VCSEL module is summarized in Table I.

Table I. Performance of the 2-D VCSEL module.

Items	*Performance*
Channel	16 ch (8 x 2)
Total Throughput	16 Gb/s (1Gb/s x 16ch)
Dimensions	Same as MPO Connector
Manufacturing Method	Plastic Molding
Total Eccentricity	Av. = 3.4 μm, Max. = 6.2 μm
Coupling Loss	Av. = 0.67 dB, Max. = 0.89 dB for GI-50 Fibers
Optical Crosstalk	Max. = -65 dB
Reliability	Durability for 100 Matings Max. Loss Increase = 0.26 dB

4. Block-Module Integration

Figure 4 shows an example of advanced application image using this module configuration. Users can select any combination of block modules such as the WDM, the modulator, the add-drop multiplexer, the scrambler, the isolator or PLC module inserted between the fiber connector and the LD or PD module. Such block module integration makes the system flexible, and each component can be standardized. This integration thus results in low cost.

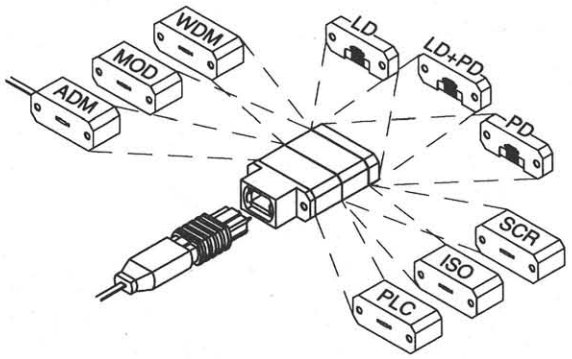

Fig. 4. Application as block module integration.

5. Hyper-Parallel Transmission using Image Fiber

The transmission channel and transmission density can be even further expanded by combining a 2-D VCSEL and an image fiber as schematically shown in Fig. 5. We have actually demonstrated 6×6-parallel transmission through an image fiber at a bit rate of 1 Gb/s/ch, and showed an optical crosstalk of less than –27 dB from dc to 3GHz and sufficient bit-error performance [14].

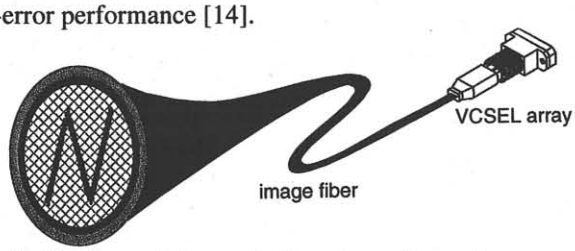

Fig. 5. Hyper-parallel transmission using an image fiber.

6. Crossbar-Switch Application

By increasing the transmission channel or channel density, new applications in addition to the parallel data links will be created. One noteworthy application is an all-optical space-division switch that acts by simply selecting the channel corresponding to the port connected to the desired destination as shown in Fig. 6. We have actually fabricated a 16ch×16ch optical full-crossbar switch, which showed a total insertion loss of 6.7 ± 1.1 dB and sufficient bit-error performance [15].

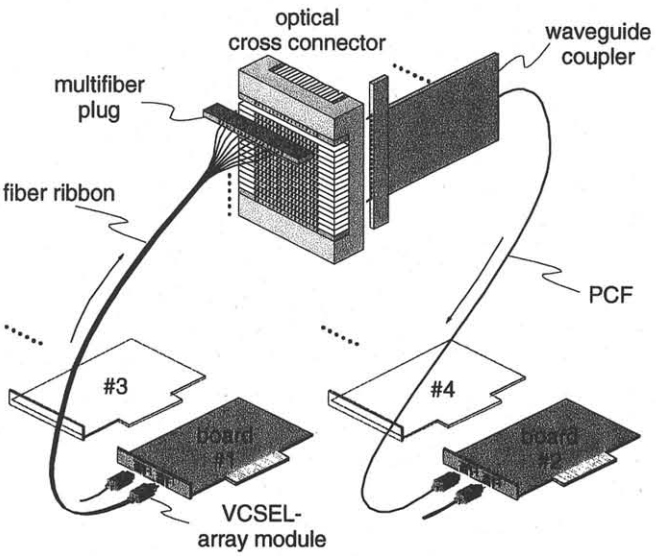

Fig. 6. Application for all-optical space-division switch.

7. Conclusions

We have developed multidimensional VCSEL modules that are push/pull-connectable to a standard MPO-compatible fiber connector. This structure has the potential to provide high-density, high-throughput optical parallel interconnections and optical space-division switches.

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