16-Channel 0.35μm CMOS/VCSEL Transmission Modules*

Chen Hongda[1], Shen Rongxuan[1], Mao Luhong[1], Tang Jun[1], Liang Kun[1], Du Yun[1], Huang Yongzhen[1], Wu Ronghan[1], Feng Jun[2], Ke Ximing[2], Liu Huanyan[2] and Wang Zhigong[2]

(1 State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, The Chinese Academy of Sciences, Beijing 100083, China)

(2 Department of Radio Engineering, Southeast University, Nanjing 210096, China)

Abstract: The vertical cavity surface emitting laser (VCSEL) arrays and VCSEL-based optical transmission modules are investigated. It includes the VCSEL's spectral characteristic, modulation characteristic, high frequency characteristic, and compatibility with microelectronic circuit. The module consists of 1×16 VCSEL array and 16-channel lasers driver with 0.35μm CMOS circuit by hybrid integration. During the test process, the module operates well at more than 2GHz in −3dB frequency bandwidth.

Key words: VCSEL; CMOS; optoelectronic integration; optical interconnects

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1 Introduction

Optoelectronic integrated circuits (OEICs) are key devices for advanced optical interconnects and optical switching networks. We can achieve good immunity against electromagnetic interference (EMI) because of their very short interconnects, reducing of chip area, improved in reliability, the cost reducing, −3dB bandwidth increasing, and so on. The high density and high performance of OEICs are expected to be used in optical interconnects massively parallel processors and optical switching networks of data communication. An optoelectronic-VLSI (OE-VLSI) circuit technology now exists for providing thousands of optical input and output to foundry-grade very large scale integration (VLSI) silicon CMOS circuitry. The technique provides a method for optoelectronic integration of optical elements and microelectronic VLSI silicon IC's. The OE-VLSI hybrid integration offers the potential for both high speed and high complexity.

As a light source, vertical cavity surface emitting lasers (VCSELs) offer the great advantages over conventional edge-emitting lasers, such as extremely low threshold current, single longitudinal mode, especially surface emission laser with very small beam divergence and simple fabrication in large two-dimensional (2D) arrays, which make VCSEL-based components that integrated photonic devices and microelectronic circuits, suit high density parallel optical interconnects and optical switching networks very well.

The most important feature of VCSEL-based photonic devices is the capability of two-dimensional

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Chen Hongda male, was born in 1960, professor, PhD. He is engaged in the research on parallel optical transeiver modules and optoelectronic circuits and system.

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integration, which can be integrated with state-of-the-art electronic circuits. Another important merit is low-cost production, because VCSELs can be made by on-wafer mirror growth, on-wafer processing, on-wafer testing, and on-wafer screening, all of which result in high yields and low costs[1].

Since VCSELs can not be grown directly onto silicon substrates, they must be attached by the hybrid integration techniques. Therefore the key to success for CMOS is the development of a reliable/manufacturable hybrid process that can bond the VCSELs directly to the circuits. Flip-chip soldering is used to hybridly integrate the optoelectronic chip epitaxial side down with silicon CMOS. In this paper, we report some investigations on vertical cavity surface emitting laser arrays and VCSEL-based optoelectronic photonic multiple chip modules (MCM), consisting of vertical cavity surface emitting laser array and 16-channel lasers driver 0.35μm CMOS circuit. The hybrid integrated MCM based on VCSEL are operated at more than 2GHz in −3dB frequency bandwidth, which could be used in free space optical interconnects (FSOI).

2 VCSEL structure

The performance characteristics of VCSELs are strongly influenced by the epitaxial struture and fabrication processes that are employed, so the processing technologies producing laser structures have significant impact. The device cross-section of a vertical cavity surface emitting laser is shown in Fig. 1. The epitaxial structure is grown on a n-GaAs substrate by metalorganic chemical vapor deposition (MOCVD). It consists of a 32-pair n-doped $Al_{0.9}Ga_{0.1}As$/GaAs quarter-wave distributed Bragg reflector (DBR), a one- wavelength $Al_{0.3}Ga_{0.7}As$/GaAs/$In_{0.2}Ga_{0.8}As$ resonant cavity, a one-wavelength p-doped contact layers formed from $Al_{0.98}Ga_{0.02}As$ current constriction layer and GaAs intra-cavity contact layer and a 22-pair $Al_{0.9}Ga_{0.1}As$/GaAs quarter-wave DBR. The active region contains three $In_{0.2}Ga_{0.8}As$ quantum wells of thickness 8nm with adjacent GaAs barriers of thickness 10nm. The main VCSEL processing steps include etching the circular mesas of the p-type GaAs contact and the current constriction layer for oxidation, lateral oxidation in wet-oxidation and evaporate the metals for p-type and n-type contacts. First, the top DBR is selectively wet etched into diameter of 28μm circular mesas to the p-type GaAs contact layer. Then diameter of 50μm circular mesas are formed by wet chemical etching. A current aperture defining the active diameter of 10μm is provided by selective oxidation. This is a good device structure for studying the reflectivity-dependent laser characteristics because the top DBR is composed of binary materials ($Al_{0.9}Ga_{0.1}As$/GaAs) with abrupt interfaces and can be selectively removed one pair once[2,3]. The VCSEL is operated at 850nm wavelength, 3mA threshold current, and 1~3mW output optical power. In practical application, we can fabricate a variety of linear arrays or two-dimensional arrays based on different needs. In our experiment, we adopted the 1×16 linear array.

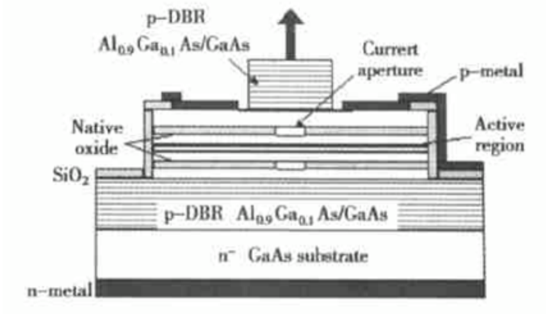

Fig. 1 Cross-section of VCSEL device

3 Hybrid integrated CMOS/VCSEL multiple chip modules

VCSEL-based transmission modules are optoelectronic devices that have some optical units and electronic processing circuitry. In the transmission module, each VCSEL requires a driver circuit whose current drive capacity matches the characteristics of the VCSEL. VCSEL arrays in a surface normal optical fashion become important to improve the VCSEL-based OE-VLSI technology, which are integrated optoelectronic circuits by providing the VCSEL arrays with state-of-the-art silicon CMOS circuitry. Designing VCSEL-based transmission modules, not only requires high performance components and techniques of integrating, but also requires consideration of methods for the optical I/O routing, array mounting, and thermal heat sinking. In addition the cost, size, weight, testability, and manufacturability play important roles in the design of such a commercial product. For example, in order to conserve space, the VCSEL should be placed on the top of upper dielectric layer and located in or very near the pixel to reduce parasitic factors and lead length.

We design and fabricate the hybrid integrated CMOS/VCSEL multiple chip modules. The circuits are designed using 0.35μm CMOS (MOSIS) technics. For CMOS circuits, the processing functions of the transmission utilize minimum size transistors in order to conserve space, increase speed, and reduce power dissipation. These transistors have low current sinking capability, but the VCSELs require several milliamps of drive current[2]. Thus, a buffer circuit must be provided to match the processing circuit to the VCSEL. In addition it is necessary to provide a current to bias the VCSEL to I_{th}. Figure 2 shows our circuit schematic of 1-channel VCSEL driver. M1 and M2, M9 and M3, M10 and M4, M11 and M12 form a current source separately. M13 and M14 form a phase inverter. By changing the value of V_{th}, we can control the drain voltage. Because M11(M12) situate at linear working area, the drain current would be changed with drain voltage. M3(M10) act as constant current source for their saturation state. The W/L of M9 is much larger than that of M3, so the output current of M9 is larger too. Changing the W/L of M9(M3), 2mA current(threshold current) can be got. The way to generate modulation current is in a similar way. The voltage range of V_{th} and V_{mod} is 0~5V. We also designed and fabricated 16-channel 0.35μm CMOS VCSEL driver circuit chip by MOSIS, the photo is shown in Fig. 2.

We have investigated the match and compatibility of VCSEL and CMOS driver circuits, the integration of OEICs, and the hybrid integration of photonics devices and multiple chips. The hybrid integrated VCSEL-based optical transmitter modules are fabricated successfully. Some optoelectronic characteristic of the modules are measured. Figure 3 is the L-I-V characteristic of 1×16 VCSEL array. At the same time, we demonstrate the 16-channel laser simultaneous working in the hybrid integrated CMOS/VCSEL multiple

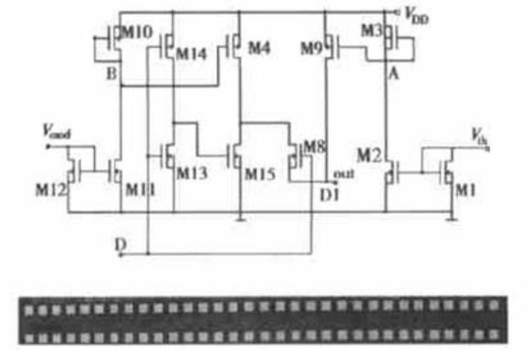

Fig. 2 Circuit schematic of 1-channel VCSEL driver and 16-channel 0.35μm CMOS circuit chip

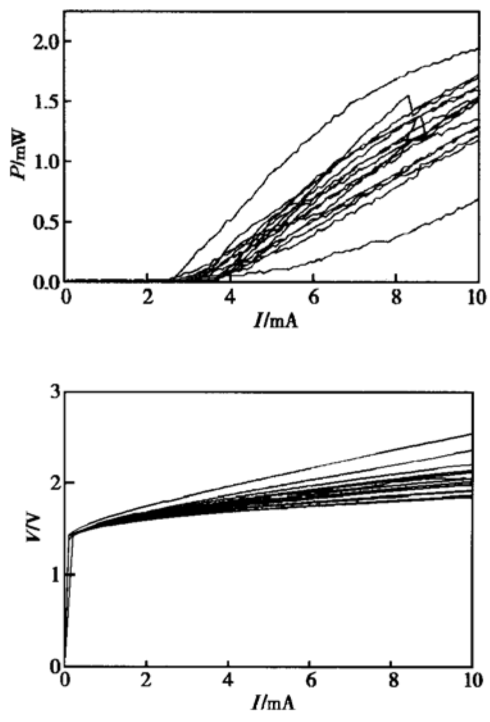

Fig. 3 L-I-V characteristic of 1×16 VCSEL array

chip modules, as shown in Fig. 4. The modules have approved optoelectronic characteristics and uniformity. Figure 5 shows the frequency characteristics of the modules measured by the HP8757C scalar network analyzer. The measurement of the −3dB frequency bandwidth is more than 2GHz.

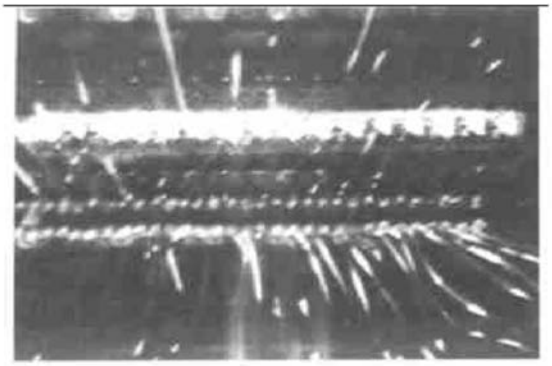

Fig. 4 16-channel laser simultaneous working in the hybrid CMOS/VCSEL modules

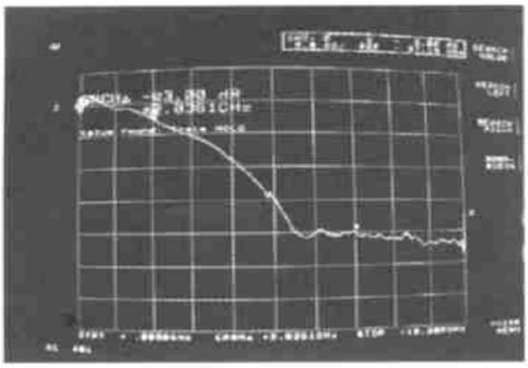

Fig. 5 Frequency characteristic of the hybrid CMOS/VCSEL modules

4 Conclusions

Vertical cavity surface emitting lasers have unique features and the capability of two-dimensional integrated with state-of-the-art electronic circuits[4,5]. But there are still many special problems about OEICs process to solve. At present, the investigation is in its growing period and has large perspective. Now many corporations are developing their research projects about it. In the future, VCSEL-based transmission components integrating photonic devices and microelectronic circuits would be very well suitable for high density parallel optical interconnects and optical switching networks.

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16 信道 0.35μm CMOS/VCSEL 光发射模块*

陈弘达[1]　申荣铉[1]　毛陆虹[1]　唐　君[1]　梁　琨[1]　杜　云[1]　黄永箴[1]　吴荣汉[1]
冯　军[2]　柯锡明[2]　刘欢艳[2]　王志功[2]

(1 中国科学院半导体研究所 集成光电子学国家重点联合实验室, 北京　100083)
(2 东南大学射频与光电集成电路研究所, 南京　210096)

摘要: 研究了垂直腔面发射激光器(VCSEL)及其列阵器件的光谱特性、调制特性、高频特性及与微电子电路的兼容性, 将 1×16 的 VCSEL 与 CMOS 专用集成电路进行多芯片组装(MCM), 混合集成为 16 信道 VCSEL 光发射功能模块. 测试过程中, 功能模块的光电特性及其均匀性良好, 测量的 − 3dB 频带宽度大于 2GHz.

关键词: 垂直腔面发射激光器; CMOS; 光电子混合集成; 光互连
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陈弘达　男, 1960 年出生, 研究员, 博士, 主要从事并行光发射接收模块和光电子集成电路与系统研究.
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