

Optoelectronic Smart Pixels Comprising Flip-Chip-Bonded GaAs/AlGaAs MQW Detectors and Modulators on Silicon CMOS Circuit*

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Abstract: Optoelectronic smart pixels with hybrid integration of GaAs/AlGaAs multiple quantum well (MQW) detectors and modulators arrays have been made, which are flip-chip bonded directly on the top of 1 μ m silicon CMOS circuits. This enables an achievement of Optoelectronic Integrated Circuits (OEIC) as well as does the design and optimization of CMOS circuits and GaAs/AlGaAs MQW devices to proceed independently.

Key words: MQW; photodetector; modulator array; CMOS; flip-chip bonding; OEIC; smart pixels

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1 Introduction

A high-density and high-performance optoelectronic integrated circuit (OEIC) is expected to be used in data communication in massively parallel processors of optical interconnects and optical switching networks. The most desirable optoelectronic integrated circuit is the state-of-the-art circuit, unaffected by the integration with optoelectronics. Smart pixels are optoelectronic devices that have one or more optical input and/or outputs, in-

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cluding the electronic processing circuit, which are usually integrated into two-dimensional arrays in a normal surface optical fashion.

In past few years, the hybrid technologies have developed into the mode attaching GaAs/AlGaAs multiple quantum well (MQW) devices, which act as both photodetector and optical modulators, to prefabricated silicon integrated circuits^[1-3]. It enables OEIC to be achieved and the design and optimization of CMOS circuits and GaAs/AlGaAs MQW devices to proceed independently^[4]. The GaAs/AlGaAs MQW modulators and photodetector may operate in high speed processing and with a high density optical input/output. The incorporation of GaAs/AlGaAs MQW optical I/O devices with CMOS circuit plays an important role in terms of the density of optoelectronic smart pixel arrays^[5], which could be used in the optical interconnects and switching systems.

2 MQW Devices Structure

The multiple quantum well devices with a pin MQW structure is grown by molecular beam epitaxy. The I-MQW consists of 90 periods of 8.5nm GaAs wells and 4nm Al_{0.3}Ga_{0.7}As barriers. The multiple quantum well modulators are based on quantum confined Stark Effect which shows the shift of exciton peak and the change in the absorption coefficient in quantum well under the applied electric field. We calculate the absorption coefficient and the change in refractive index of the quantum well under different electric field and the e-hh exciton peak at approximate 847nm in normal operation. Since the P-pads metal of the modulators is used as an integral reflector, there exists not bottom semiconductor Distributed Bragg Reflector (DBR) for the flip-chip bonding MQW devices, and the reflectivity of this device is lower than that of the reflective modulator with bottom DBR. So, in order to increase the absorption of the intrinsic region, the number of quantum well periods is defined as 90 pairs and the thickness of AlGaAs barriers decreased to be operation voltage.

3 Optoelectronic Smart Pixels Circuit

The circuits are designed during a 1 μ m CMOS process, which consist of trans-

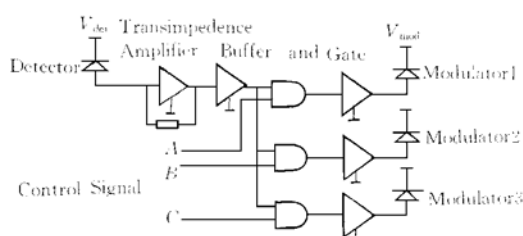


FIG. 1 Schematic Diagrams of Smart Pixels

simpedance receiver, switching nodes and modulator driver, as shown in Fig. 1. One MQW device are used for input light detector and other three for output light modulators. The control signals of A-C are used for selecting output light modulators. The input phase of the receiver consists of a reverse-biased MQW photodetector and an inverter connected. The re-

ceiver has four amplification stages, with the first being of the transimpedance amplifier and inverter-based amplifiers in the following three stages. The input receiver can be operated in single-ended mode with a single MQW diode generating positive photocurrent, small input swings are amplified to logic levels at three gain stages of the receiver output which generate photocurrent by the detector in the input transimpedance stage. Other three MQW devices served for output-light modulators and are operated by output driver at 850nm wavelength. We have made a optoelectronic smart pixels device being a Si-chip size of $7\text{mm} \times 2.4\text{mm}$, with a 1×20 array of MQW optoelectronic devices arranged in a $6\text{mm} \times 1\text{mm}$.

A cross sectional schematic of a bonding chip is shown in Fig. 2. The MQW detectors and modulators are produced in GaAs chips, whose n and p contacts are coplanar, and silicon CMOS chips are fabricated from $1\mu\text{m}$ linerules foundry facility. A precision bonding machine is employed in the chips as well.

The total height of the front of GaAs MQW device from the

surface of CMOS chip is approximate $10\mu\text{m}$. The best MQW modulators operate at a wavelength of 850—860nm. However, the GaAs substrate of MQW device is opaque at the wavelength. Therefore, the substrate is removed after the bonding to avoid excess absorption in the substrate^[2]. Epoxy then flow between the chips to ensure the mechanical stability and protect the front surface of chips during the removal of the GaAs substrate. Following this, the GaAs substrate is removed, with the p-i(MQW)-n devices attached their respective contact pads left behind. With this method, small MQW modulators and detectors are attached by flip-chip solder bonding to silicon CMOS circuits, along with the subsequent removal of the substrate, at the allowing operation of 850nm.

Measurement results prove the good optoelectronic characteristics of MQW device arrays and receiver-transmitter circuit. Figure 3 shows the eye pattern of transimpedance receiver-transmitter circuit operating at a frequency of 100MHz. The microspot reflectivity and photocurrent measurements have been used to characterize 2D exciton absorption in MQW array devices. Figure 4 shows the microspot reflectivity spectrum at 0 and 5V biases of MQW device after flip-chip bonding. Because of the strong exciton absorption, the reflectivity at wavelength of 853nm is the minimum under zero fields, which can be used as a photodetector in input windows. On the other hand, being the light modulators in output windows increased with the applied field, the MQW reflection modulator contains Quantum

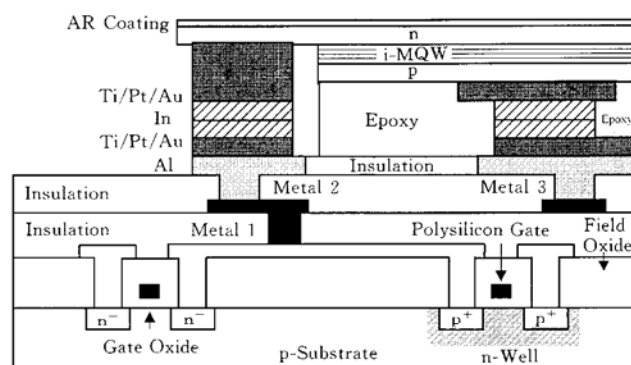


FIG. 2 Cross Sectional Schematic of a Bonding Chip

Confined Stark Effect (QCSE), causing Electroabsorption (EA) and Electrorefraction (ER), which appears as the shift of exciton peak and change of absorption coefficient in quantum well under the applied electric field. So, the reflectivity at wavelength 857nm is the minimum under an applied voltage of 5V. When the operation wavelength is 860nm, the low reflectivity is at the applied voltage of 5V and high reflectivity of 0V, and the contrast ratio varies from 1.2 : 1 to 1.5 : 1 for a 5V swing, the modulator is operating in a normal on mode.

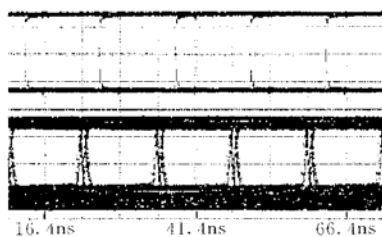


FIG. 3 Eye Patterns at 100MHz Frequency

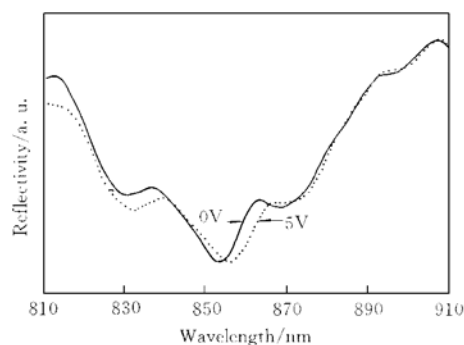


FIG. 4 Reflectivity Spectrum of Device After Flip-Chip Bonding

5 Conclusion

We demonstrate the hybrid integration of GaAs/AlGaAs multiple quantum well detectors and modulators arrays flip-chip bonding directly over the $1\mu\text{m}$ silicon CMOS circuits. The bonding pads on the silicon circuit are designed in the surface metal. After the alignment and bonding of the GaAs/AlGaAs, MQW and silicon chips are completed, GaAs substrate is removed to avoid excess absorption in substrate.

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