

## Multiple Quantum Well SEED Arrays for Flip-Chip Bonding Optoelectronic Smart Pixels<sup>\*</sup>

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**Abstract:** The investigation on GaAs/AlGaAs multiple quantum well Self Electro-optic Effect Device (SEED) arrays for flip-chip bonding optoelectronic smart pixels has been reported. In order to increase the absorption of the intrinsic region, the number of quantum well periods is defined as 90 pairs. The GaAs/AlGaAs multiple quantum well devices are designed for 850nm operation. The measurement results under applied biases show the good optoelectronic characteristics of elements in SEED arrays.

**Key words:** multiple quantum well; photodetector; space light modulator; SEED array

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### 1 Introduction

A modulator-based optoelectronic-very large scale integration (OE-VLSI) circuit technology, being developed at Bell Laboratories<sup>[1,2]</sup>, is now existing and providing thousands of optical input and output to foundry-grade VLSI silicon CMOS circuitry<sup>[3]</sup>, which makes optoelectronic integration of optical elements and microelectronic VLSI silicon IC's achieved. According to the technology<sup>[4]</sup>, GaAs Multiple Quantum Well (MQW) modulators and detectors are attached to a pre-fabricated silicon integrated circuit by hybrid flip-chip solder bonding technique, which is well established and followed by the substrate removal of GaAs chips so as to allow of the surface-normal operation up to more than thousands in optical modulators and detectors at wavelength of 850nm. The silicon integrated circuit is state-of-the-art and the unaffected by the integration process; and the

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construct, design and optimization of both chips in CMOS circuits and GaAs MQW devices can proceed independently of the placement or bonding of MQW self electro-optic effect devices (SEEDs) arrays chip to the silicon CMOS chip.

The GaAs/AlGaAs MQW SEEDs share in much of the work in smart pixels, because MQW devices can operate as both optical reflection modulators and detectors, and large scale arrays can be fabricated with a high yield. The GaAs/AlGaAs MQW modulators can operate at a high speed (i. e.  $\sim$  Gb/s)<sup>[5]</sup> or even higher at 850nm. Therefore, it is important to improve the SEED-based OE-VLSI technology.

## 2 GaAs/AlGaAs MQW Structure

The MQW SEEDs are based on the quantum confined Stark effect, which shows a shift of exciton peak and a change in absorption coefficients in quantum wells under applied electric field<sup>[6,7]</sup>. Since it has no bottom semiconductor Distributed Bragg Reflector (DBR) for the flip-chip bonding SEED, the P-pads metal of the SEEDs is used as an integral reflector, whose reflectivity is lower than the reflective modulator with bottom DBR. So in order to increase the absorption of intrinsic region, the number of quantum well periods is chosen in as 90 pairs and the thickness of AlGaAs barriers decreased to decrease the operation voltage. We calculate the variations in absorption coefficient and refractive index of the quantum well under different electric field, with e-hh exciton peak at approximately 847nm in normal-on operation.

	10nm	GaAs	P+
	200nm	Al <sub>0.3</sub> Ga <sub>0.7</sub> As	P
	20nm	Al <sub>0.3</sub> Ga <sub>0.7</sub> As	i
90×	8.5nm	GaAs	i
	4nm	Al <sub>0.3</sub> Ga <sub>0.7</sub> As	i
	20nm	Al <sub>0.3</sub> Ga <sub>0.7</sub> As	i
	1.5μm	Al <sub>0.3</sub> Ga <sub>0.7</sub> As	N
	20nm	GaAs	N
	137nm	AlAs	N
	300nm	GaAs Buffer	N
	N+	Substrate	

FIG. 1 Multiple Quantum Well Structure.

Al<sub>0.3</sub>Ga<sub>0.7</sub>As spacer and a 10nm p<sup>+</sup> ( $1 \times 10^{19} \text{ cm}^{-3}$ ) GaAs layer are grown in turn.

We calculated the variation in absorption coefficient and refractive index of the quantum well under different electric field, with e-hh exciton peak at approximately 850nm in normal-on operation<sup>[8]</sup>.

## 3 SEED Arrays and Measurement Results

We have made  $1 \times 20$  reflection-mode, surface-normal GaAs/AlGaAs MQW

Self electro-optic effect devices with pin MQW structure, shown in Fig. 1, has been grown by molecular beam epitaxy. On a n-GaAs substrate, the first 300nm of n ( $5 \times 10^{18} \text{ cm}^{-3}$ ) GaAs buffer is grown, followed with 137nm of n ( $5 \times 10^{18} \text{ cm}^{-3}$ ) AlAs stop-etch layer and 20nm of n ( $5 \times 10^{18} \text{ cm}^{-3}$ ) GaAs. Then 1.5μm n ( $5 \times 10^{18} \text{ cm}^{-3}$ ) Al<sub>0.3</sub>Ga<sub>0.7</sub>As and 20nm i Al<sub>0.3</sub>Ga<sub>0.7</sub>As spacer are grown, so is the i MQW, which consists of 90 periods of 8.5nm GaAs wells and 4nm Al<sub>0.3</sub>Ga<sub>0.7</sub>As barriers. At last, the

absorption SEED array devices for flip-chip solder bonding optoelectronic smart pixels. Some MQW SEED devices are used for input-light detectors and others as output-light modulators, which are designed for 850nm wavelength operation. The center to center spacing of the pixels is  $300\mu\text{m}$ . Each device mesa is about  $160\mu\text{m} \times 60\mu\text{m}$  in size and each consists of a  $40\mu\text{m} \times 40\mu\text{m}$  P-pad and a  $40\mu\text{m} \times 40\mu\text{m}$  N-pad. The bump-bond pad sizes and optical windows sizes are  $26\mu\text{m} \times 26\mu\text{m}$ . The active region of the device was the P-pad which also serve as a reflector. The  $1 \times 20$  MQW SEED array size is  $6\text{mm} \times 1\text{mm}$ . Figure 2 shows a microphotograph of a part of the  $1 \times 20$  SEED array and Fig. 3 shows a microphotograph of a SEED device in  $1 \times 20$  SEED array.

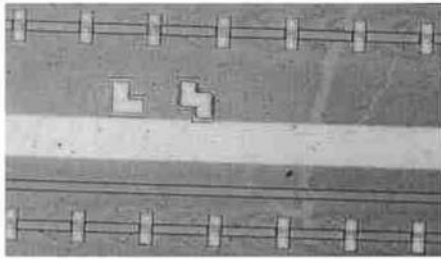


FIG.2 Microphotograph of Part of  $1 \times 20$  SEED Array

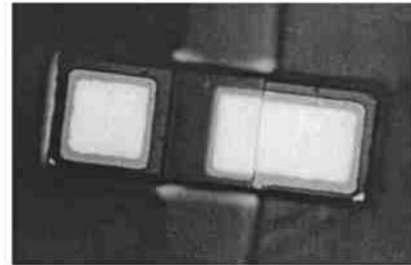


FIG.3 Microphotograph of SEED Device in  $1 \times 20$  SEED Array

We have investigated the physical effects of electroabsorption and electrorefraction caused by QCSE<sup>[9]</sup> and their mutual compatibility for the optimum performance of the devices. The photoluminescence and microspot photocurrent measurements have been used to identify the quality of grown MQW materials and to characterize the 2D exciton absorption in MQW array devices. The photoluminescence(PL) spectra are shown in Fig. 4, which were measured from the one end of the wafer to another separated laterally by 3mm, and used to determine the uniformity and the location of exciton absorption peak.

In Fig. 5, we show the photocurrent spectra of a SEED under different reverse bias, which were measured with microspot measurement system, to characterize the exciton absorption and the mode in MQW array devices. Near 850nm, a photocurrent varies from 25% to 65% for a 0V to 8V bias swing, which means the change in absorption coefficient and red-shift of exciton peak for symmetric wells under an electric field perpendicular to the quantum wells. For MQW SEED devices, the breakdown voltage(> 30V) under applied biases measurements and dark current of approximately 10nA indicate the good electronic uniformity of elements in SEED arrays. More measurements on CMOS-SEED smart pixels are carried out and the results will be published soon.

#### 4 Conclusions

We report our investigation on GaAs/AlGaAs MQW SEED arrays for flip-chip

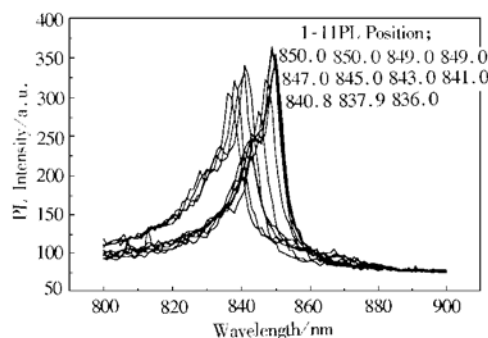


FIG. 4 Photoluminescence Spectra Measurement

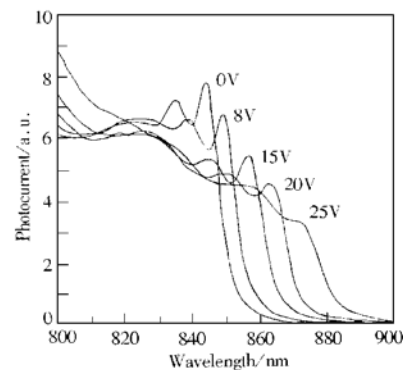


FIG. 5 Photocurrent Spectra of SEED

bonding optoelectronic smart pixels with integrated optical detectors, modulators, and electronic circuits. The GaAs/AlGaAs MQW devices are designed for 850nm operation, with some devices used as input light detectors and others as output light modulators. The characteristics of the devices indicate the good performance of the elements in SEED arrays.

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