MC3

THREE DIMENSIONAL INTEGRATED CIRCUITS: EPITAXIAL LIFT OFF GaAs PHOTODETECTORS INTEGRATED DIRECTLY ON TOP OF SILICON CIRCUITS

C. Camperi-Ginestet, Y.W. Kim, N.M. Jokerst, M.G. Allen, and M.A. Brooke
School of Electrical Engineering
Microelectronics Research Center
Georgia Institute of Technology
Atlanta, GA 30332-0250
Tel. (404)-894-8911

To overcome the interconnection limitation between devices in the plane of integrated circuits, massively parallel interconnection in three dimensions between planes of circuitry and for input/output is desirable. Using the three dimensional integration technique described herein coupled with thin film device array alignment and deposition [1], each device in arrays of thin film devices can be connected to Si circuitry for massively parallel processing. This three dimensional integration enables the simultaneous data transfer and signal processing of all data points in an array, increasing the throughput and speed of computational systems. For example, optical imaging arrays will benefit from parallel connection of each detector to signal processing circuitry, allowing imaging arrays to be large in area and in number of devices, and to have the high throughput and reduced pinout associated with the simultaneous processing of information from each pixel in the imaging array. The capability to align arrays of devices [1] also eliminates the need for wafer scale epitaxial growth uniformity for wafer scale device integration.

The three dimensional integration of high quality gallium arsenide (GaAs) optical detectors directly on top of silicon (Si) circuitry is presented in this paper. Using a modified epitaxial lift off (ELO) technique [1], a GaAs thin film optical detector is deposited on top of a layer of planarizing, insulating polyimide which lies between the detector and the Si circuitry. The detector and the circuitry are electrically connected through vias in the polyimide. This technology has potential for low cost and high performance systems since the circuits and devices can be independently optimized and tested before integration and since inexpensive prefabricated Si circuits are post processed with standard microelectronics fabrication techniques to integrate the thin film GaAs device layers only in the areas in which they are needed.

To demonstrate three dimensional integration, a GaAs metal-semiconductor-metal (MSM) detector was integrated directly on top of a simple silicon transresistance amplifier circuit [2]. Light incident on the surface of the MSM induces a current flow through the MSM, which appears as a voltage change at the gate of the first amplifier stage, which is amplified by the subsequent two amplifier stages. No attempt was made to optimize this circuit design for any particular MSM device.

To integrate the circuit and MSM device, the fully fabricated circuit was spin coated with 5 μm of polyimide. Using standard photolithography and reactive ion etching, 100 μm X 100 μm vias were etched in the polyimide, which fully exposed the underlying Al pads on the Si circuit. Gold was vacuum deposited on the etched substrate to electrically interconnect the underlying Si circuit to the top of the polyimide. The gold was then patterned for subsequent connection to the MSM.

To obtain the high quality, single crystal thin film GaAs devices necessary for this three dimensional integration, epitaxial liftoff (ELO) was employed. This technique utilizes the high etch selectivity between high Al concentration Al $Ga_x As_{1-x}$ materials and low Al concentration alloys [3] to separate single crystal epitaxial material and devices from the lattice matched growth substrate. An array of 100 μm X 100 μm X 0.5 μm thick GaAs ELO devices was transferred to a transparent polyimide diaphragm for alignable and selective deposition [1] onto the polyimide planarized Si circuit. When the GaAs was deposited onto the host substrate, it was van der Waals bonded onto the Au fingers on the polyimide to form the MSM detector, forming a Schottky barrier electrical contact and a stable mechanical bond between the Au and the GaAs, thus completing the three dimensional structure. Figure 1 shows a photomicrograph of fully fabricated device, with the GaAs on top of the metal fingers.

The response of the circuit was tested using pulsed (square wave) 850 nm laser light from a Hewlett Packard HP8153A lightwave multimeter delivered through an optical fiber directly to the MSM. No illumination of the surrounding circuit occurred during this test. The resulting output signal was a square wave with a rise time of approximately 8 μsec and a fall time of approximately 12 μsec. This performance is typical for such a simple, unoptimized amplifier circuit. When the input optical signal was moved from MSM to the adjacent Si circuitry or when the circuit was incorrectly biased, no output signal was observed.

[1] C. Camperi-Ginestet, M. Hargis, N. Jokerst, M. Allen, accepted in *IEEE Phot. Tech. Lett.*, December, 1991.
[2] M.G. Allen, A. Nikolich, M. Scheidl, and R.L. Smith, *Sensors and Actuators*, A21-A23, pp. 211-214, 1990.
[3] E. Yablonovitch, T. Gmitter, J. P. Harbison and R. Bhat, *Appl. Phys. Lett.*, 51, pp. 2222-2224, 1987.

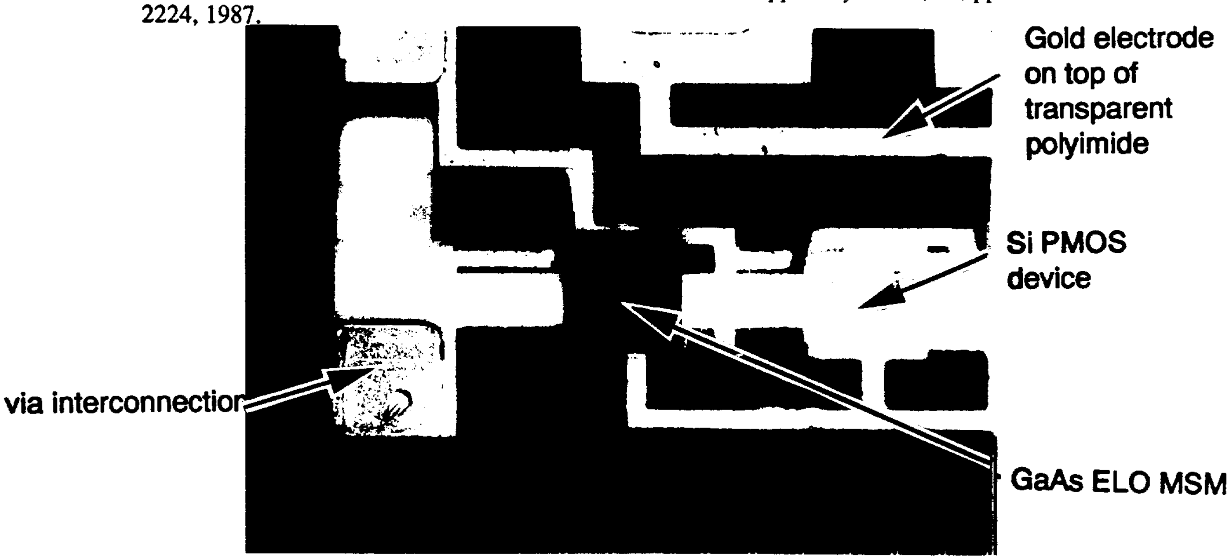

Figure 1. Photograph of the fabricated three dimensional vertical integration. The GaAs ELO material has been contact bonded to the Au MSM fingers which lie on top of polyimide planarized Si circuitry.