Integration of Thin Film Optoelectronic Devices onto Micromachined Movable Platforms

Scott T. Wilkinson, Young W. Kim, Nan M. Jokerst, and Mark G. Allen

Abstract—**The integration of a thin film optoelectronic device onto a micromachined movable platform is reported in this letter. This micro-opto-mechanical system, consisting of a thin film AlGaAs/GaAs double heterostructure *p-i-n* detector integrated onto a polyimide micromachined platform on silicon, has applications which range from fiber optic coupling to sensors. Fiber optic coupling is demonstrated using a stationary fiber positioned above the thin film detector. By applying a voltage between the platform and actuation strips, the platform moves and a change in fiber to detector coupling is observed.**

I. INTRODUCTION

THE integration of compound semiconductor emitters and detectors with micromachined devices to form micro-opto-mechanical systems (MOMS) offers significant opportunities in applications ranging from fiber optic couplers to sensors. These applications include integrated microactuators used to position photonic devices for improved coupling in highly position sensitive optoelectronic packages. In the optoelectronics industry, labor-intensive alignment of fibers to emitters or detectors is expensive and time-consuming, thus the cost of fiber optic pigtailed products is often significantly higher than the sum cost of the components. In the few microactuator alignment systems which are currently emerging for optoelectronic packaging, the fibers are positioned with the microactuators. These techniques typically employ high-voltage piezoelectric motion because of the relatively large mass of the fiber and the distances traversed [1]. An alternative solution is an emitter/detector to fiber alignment system in which the optoelectronic device is translated relative to a stationary optical fiber. This type of automated system can be realized using the integration of micromachined devices, thin film optoelectronic devices, and silicon feedback circuitry.

Previous work aimed at MOMS has focused almost exclusively on the micromachining of monomaterial systems such as gallium arsenide [2], [3]. Although several interesting structures have been fabricated using this monomaterial approach, there are many advantages, both in cost and in performance, in using mixed material systems. Mixed material systems allow the use of an optimal material for each function, for example, silicon for circuits, polymers or other suitable materials for micromachined devices, and compound semiconductors for optoelectronic devices. Spin-deposited polymers for micromachined devices can be easily integrated onto silicon, however, the integration of the compound semiconductor device with the micromachined device is more problematic. It is very difficult to grow single crystal compound semiconductor material on silicon due to growth constraints such as lattice matching, and the growth of compound semiconductors onto materials which do not have lattices, such as polymers, has not been demonstrated. Alternatively, the compound semiconductor optoelectronic devices could be grown on a lattice matched substrate and simply attached to the micromachined device. The problem with this approach is that the weight of the compound semiconductor devices with the growth substrate attached may significantly impede the range of motion of the micromachined device.

In this letter, we report the integration of light weight thin film GaAs-based devices with movable polyimide-based micromachined devices. This MOMS device demonstrates variable fiber to detector coupling using the electrical actuation of a micromachined movable platform with a single crystal thin film photodetector integrated onto the platform. The movable micromachined platform [4] is constructed of polyimide, a flexible material with excellent micromachining properties, on a silicon substrate. By bonding a semiconductor thin film GaAs-based detector onto the movable micromachined platform, this system forms a micro-opto-mechanical system which combines all of the potential advantages of silicon electronics and the realized advantages of polyimide micromachining materials with optoelectronics. Through the appropriate application of external voltages between the platform and actuation strips, these platforms can be actuated in both the vertical and lateral directions by as much as 50 μm and 5 μm (10% of vertical), respectively. The thin film optoelectronic device is formed by separating the epitaxial detector from the growth substrate, and the resulting light weight thin film device does not interfere with the movement of the platform. As the platform, and thus, detector, moves vertically relative to a fixed optical fiber, the optical coupling varies.

II. FABRICATION

Surface micromachined platforms were fabricated using standard microfabrication techniques, as illustrated in Fig. 1. An array of gold actuation strips and contact pads were defined on an electrically isolated oxidized silicon wafer. These strips were insulated with a layer of spun on DuPont PI 2611 polyimide, which was cured at 350°C for 1 hour. A 2.5 μm

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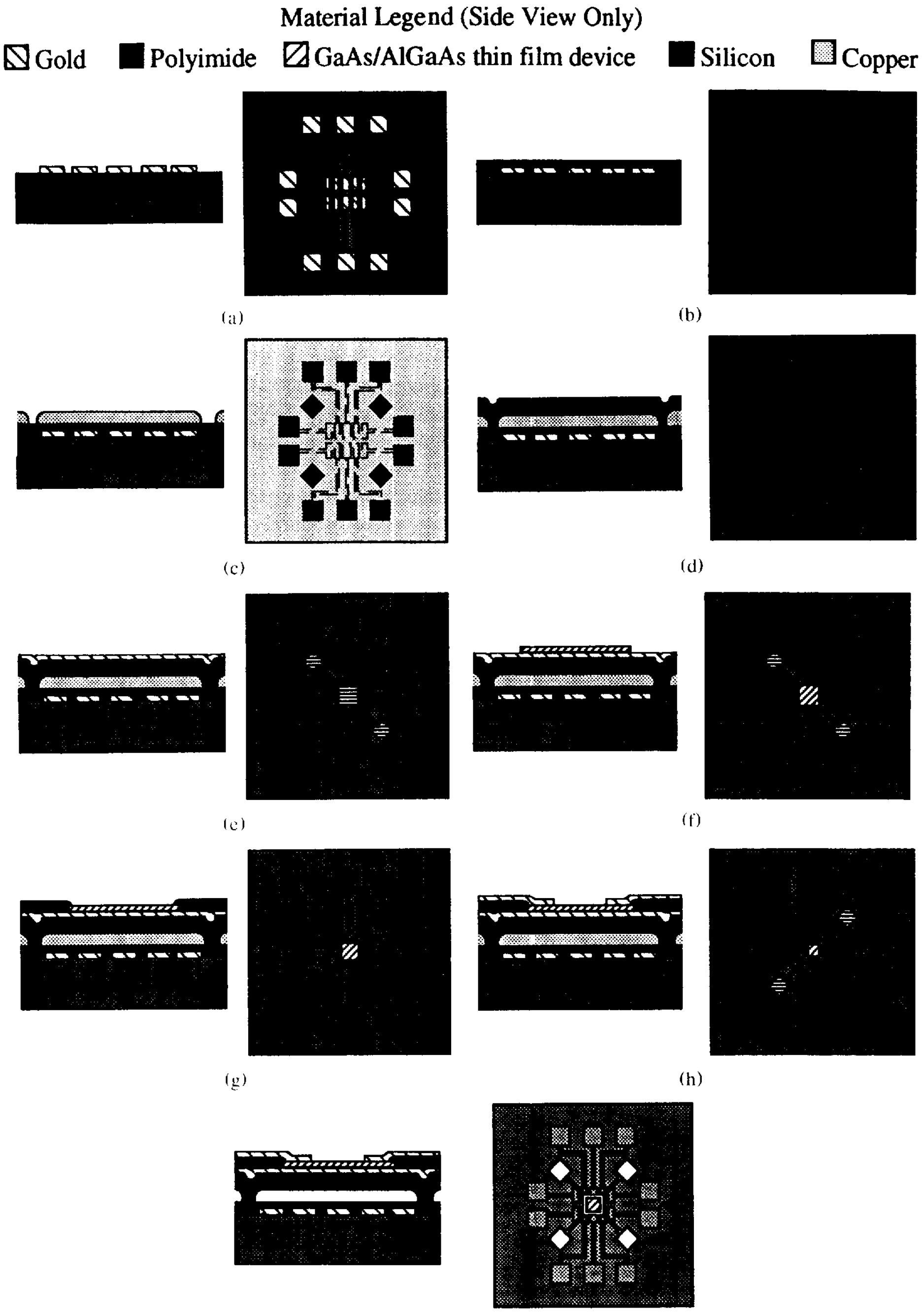
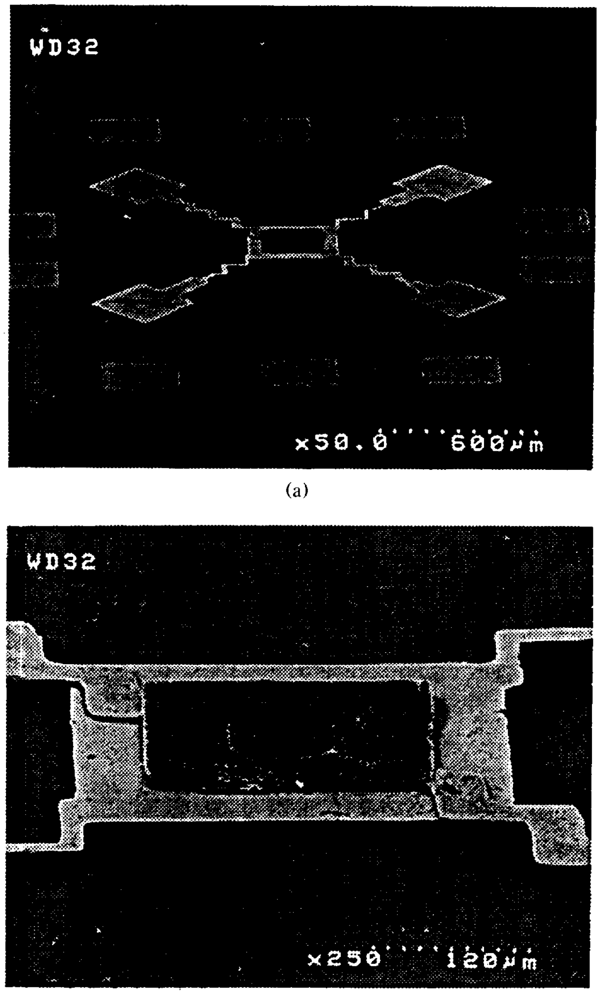


Fig. 1. MOMS Processing Sequence. Top views on the left, side views on the right. (a) Au actuation strips on insulated Si wafer; (b) insulating polyimide layer spun on; (c) Cu release layer deposited and defined; (d) polyimide platform layers spun on; (e) bottom contact deposited and defined; (f) thin film optoelectronic device bonded onto bottom contact layer; (g) insulating polyimide layer spun on and via opened; (h) top contact deposited and defined; (i) after platform definition, Cu sacrificial layer removed.

copper release layer was vacuum deposited on top of the polyimide, and holes were defined in this copper layer so that the pads at the ends of the platform legs would be in contact with the polyimide below. Two layers of PI 2611 were then spun onto the release layer and cured at 350°C for 1 hour to form the platform layer. Titanium and gold layers were next vacuum deposited onto the polyimide layers and patterned to define the square platform and two of the 40 μm wide accordion platform legs. These two gold-coated legs form a contact which runs from the bottom of the thin film detector (i.e., the top of the platform) to two pads which are attached to the silicon surface. The platform shape and size were defined by these bottom contact layers and by the top contact layers and the transferred thin film detector.

The next step in the integration process was to integrate the thin film detector onto the metallized polyimide platform. The semiconductor photonic devices used in this work were thin film AlGaAs/GaAs/AlGaAs double heterostructure *p-i-n* devices. These high quality single crystal structures were grown lattice matched on top of a sacrificial AlAs layer which had been grown lattice matched to a GaAs substrate. The as-grown layer structure was GaAs (substrate)/AlAs (undoped, 0.2 μm thick)/$Al_{0.3}$ $Ga_{0.7}As$ ($n = 3 \times 10^{7}$ cm^{-3}, 0.5 μm thick)/GaAs ($n < 10^{14} cm^{-3}$, 1.1 μm thick)/$Al_{0.3}Ga_{0.7}As$($p = 1.3 \times 10^{19} cm^{-3}$, 0.5 μm thick). Using the transfer diaphragm epitaxial liftoff procedure [5]–[8], a 250 μm × 250 μm AlGaAs/GaAs/AlGaAs thin film device with a bottom ohmic contact (AuZn/Au) was aligned and bonded onto the gold coated platform with two defined legs. The high quality of these single crystal thin film devices has been verified by a number of researchers [9]–[11]. An insulating layer of polyimide was then spun onto the platform and thin film detector, and a window for a top electrical contact to the device was etched in the polyimide using reactive ion etching (RIE). The top ohmic contact (AuGe/Ni/Au) was deposited and patterned such that it defined the two legs of the platform that were not defined by the bottom contact. This top contact had a window in the center of the thin film detector to allow optical access to the photonic device. An aluminum mask was then deposited and patterned to protect the thin film device, and the polyimide was removed using RIE except where it was masked by the top and bottom contacts and thin film device. The platform with the integrated device was released from the substrate by etching away the copper layer in a $FeCl_3$ solution, resulting in a polyimide platform suspended on four flexible polyimide legs with an electrically connected, integrated thin film detector. Note that the actuation strips, which are used to electrostatically move the platform, lie underneath the platform beneath the first layer of polyimide. Electron photomicrographs of this completed MOMS device are shown in Fig. 2. Fig. 2(a) shows the entire MOMS device while Fig. 2(b) is a close-up of the thin film detector on the polyimide platform.



(a)

(b)

Fig. 2. Photomicrographs of MOMS Devices (a) Photomicrograph of entire MOMS device consisting of a 250 μm × 250 μm AlGaAs/GaAs/AlGaAs *p-i-n* double heterostructure detector integrated onto a polyimide movable platform; (b) close-up view of the detector.

III. RESULTS

Variable coupling from an optical fiber to the detector on the platform was measured as a function of platform actuation voltage, i.e., platform vertical position. Platform horizontal position was variable by less than 0.25 μm in this initial device, so coupling changes due to platform lateral displacement were negligible. A single mode optical fiber with a core diameter of approximately 8 μm was initially aligned at the edge of the top contact window a few microns above the device. For testing of both actuation and detection, the bottom contact of the thin film detector, which is also the platform contact, was connected to ground. In this configuration, independent voltage sources were used to apply a bias across the thin film detector and a bias between the platform and actuation strips. This configuration is important since voltage and current spikes from a high voltage actuation source could damage a thin film detector. Application of a voltage to the actuation strips below the platform moved the platform toward the silicon substrate due to electrostatic attraction. The movable platforms initiated actuation at an applied voltage of 240 V and ceased actuation at an applied voltage of 320 V. The vertical actuation distance was 2.5 μm in this first demonstration, but varying vertical and horizontal actuation ranges can be attained by changing the copper sacrificial layer fabrication thickness. The fiber was not lensed, and as the platform moved down, more of the light was coupled into the detector. As expected, the detector photocurrent increased as the platform moved downward with applied actuation voltage, as shown in Fig. 3, since the

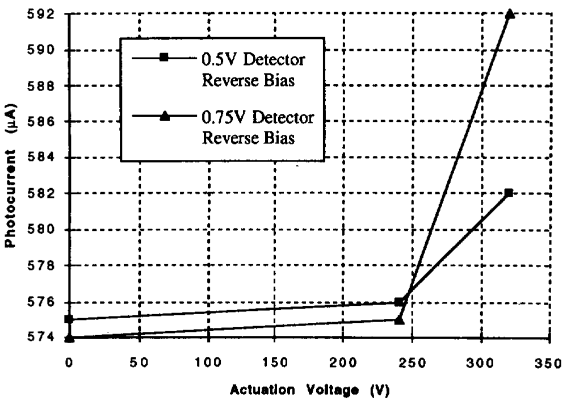


Fig. 3. Measured detector photocurrent as a function of applied platform actuation voltage with the detector under a reverse bias of 0.5 Volts and 0.75 Volts.

platform was moved further from the fiber. To ensure that this change in detected photocurrent was due to platform actuation, the light source was turned off and the platform was actuated. In this experiment, no change in detector photocurrent was observed. Thus the change in photocurrent from the detector as a function of platform actuation is due to improved coupling with the single mode fiber.

IV. CONCLUSION

We have demonstrated the integration of a thin film detector onto a micromachined movable platform, forming a micro-opto-mechanical detector to fiber alignment system in which the detector rather than the fiber is moved. The detector photocurrent increased as more light was incident on the detector due to electrostatic actuation of the platform. By increasing the platform sacrificial layer thickness, the actuation distance can be increased in all three dimensions allowing for greater flexibility in original fiber position. Also, a larger range of motion in the horizontal direction will allow the device to be better utilized as a fiber optic coupler. In addition, the use of a different material system for the platform will reduce the high voltages needed for actuation. Although the actuation voltages in this prototype device are high, the device concept and fabrication sequences are entirely compatible with lower-voltage drive schemes such as the newly developed magnetic micromachined actuators [12]. Finally, lensing of the fiber will make alignment more critical, resulting in improved coupling. This demonstration of a micro-opto-mechanical system using thin film optoelectronic devices integrated with micromachines significantly expands the integration options for both opto-electronic and micromechanical systems and is a promising first step toward low cost automated on-chip optical fiber alignment.

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