Pt Heater/Sensor Microarray for Distributed Fluidic Cooling Assessment

Yong-Kyu Yoon and Mark G. Allen
School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta, Georgia, USA,
Phone: (404) 894-9908; Fax: (404) 894-5028; E-mail: gte163s@prism.gatech.edu

This paper presents the design, fabrication, and characterization of a one-dimensional microscale heater array, each pixel of which acts as both a heater and a resistive temperature sensor simultaneously. The heater/sensor array is designed to mimic heat generation by line arrays of vertical-cavity surface emitting lasers (VCSELs), in order to assess microfluidic cooling schemes for these laser arrays. The important attributes of this microfluidic cooling testbed are: (1) ability to simultaneously locally heat and locally sense temperature; (2) formation on a semiconductor substrate by surface micromachining, allowing in-situ experimental simulation of semiconductor devices on the substrates of interest; and (3) individual pixel sizes on the order of individual semiconductor devices. Although the devices described in this paper are designed for a VCSEL array, these attributes make this approach generally applicable to a variety of other semiconductor and/or microfluidic scenarios of interest.

The multipixel testbed exploits the extremely linear temperature coefficient of resistance of platinum (Pt) [1,2] for individual pixel temperature sensing. Since this resistance measurement is performed by passing a current through each pixel and measuring the resultant voltage developed across the Pt (i.e., a four-point measurement), each pixel can be heated by making this sense current appropriately large. Electrical addressing of each pixel allows heating and sensing at the individual pixel level, thereby enabling the application of and/or sensing of a the spatial thermal profile over the lateral extent of the array.
The particular array discussed in this paper is a linear array consisting of 100 heater elements, each of which have a 75μm pitch, and a nominal 20μm×20μm resistive heating area (which mimics typical dimensions of a VCSEL array[3]). Probe pads (a total of 101) are placed between the pixels to apply current for the heater function or to determine temperature for the sensor function. Two different types of heater pixel geometry have been fabricated, each with the same total pitch. The first is a straight line pixel with length of 20 micron and width of 3 micron; and the second is a meander pixel combined with a heat spreader, which has a total meander length of 48 microns and a width of 3μm.

The pixel array (Fig. 1) is fabricated using standard lithographic techniques. The fabrication sequence is given in Fig. 2. The starting material is an oxidized silicon substrate, although the fabrication process would also allow realization of the array on a suitably passivated compound semiconductor substrate as well. Pt (1000Å) is deposited and patterned using standard lift-off process. Next, SiO2 (4000Å) is deposited using plasma-enhanced chemical vapored deposition (PECVD). Au(2000Å) is then deposited to create a pad that aids in a more even distribution of heat. This gold is patterned by again using the lift-off process. The SiO2 for the probe pad is etched in buffered oxide etchant (BOE) and an Al layer(3000Å) is subsequently deposited using E-beam evaporation before removing the photoresist used as the SiO2 etch mask. By removing the photoresist, the Al is patterned via lift-off and the fabrication is complete. The test setup is shown in Fig. 3. The array is diced into strips of 8mm long and the 1.2mm wide. To calibrate the fabricated Pt sensor, an E-type thermocouple is positioned next to the strip.

The experimental results include the following:

(1) Very good linear temperature dependence of Pt resistance has been obtained (the temperature coefficient: 0.0414 through 25ºC to 175ºC for the straight pixel).(Fig. 4)
(2) A Pt array is heated by varying current (0~15mA) and the temperature is simultaneously sensed (Fig. 5). A curve of the temperature change due to a fan cooling has been included for comparison.
(3) A good spatial distribution of temperature sensitivity has been shown in Fig. 6. It has a 1ºC variation through the overall pixel array.
(4) Local heating and temperature sensing has been demonstrated by heating one set of pixels(10pixels) and observing the temperature distribution (Fig. 7); temperature sensing is carried out with the 10 pixel unit. (heater part has about 92ºC and right far end has 32ºC)

Reference

[1] P. Ciureanu and S. Middelhoek (edited by), "Thin Film Sensitive Sensors, in Sensors Series-Chap.4. Thermoresistive Sensors", Institute of Physics publishing, Bristol, 1992.

[2] D.A. Benson, D. Bowman, W. Filter, R. Mitchell, "Design and Characterization of Microscale Heater Structures for Test Die and Sensor Applications", IEEE InterSociety Conference on Thermal Phenomena, pp. 434-441, 1998.

[3] Y.C. Lee, S.E. Swirhun, W.S. Fu, T. A. Keyser, J.L. Jewell, W.E. Quinn, "Thermal management of VCSEL-based optoelectronic modules", Electronic Components and Technology Conference, Proceedings., 45th, Page(s): 387 –392, 1995

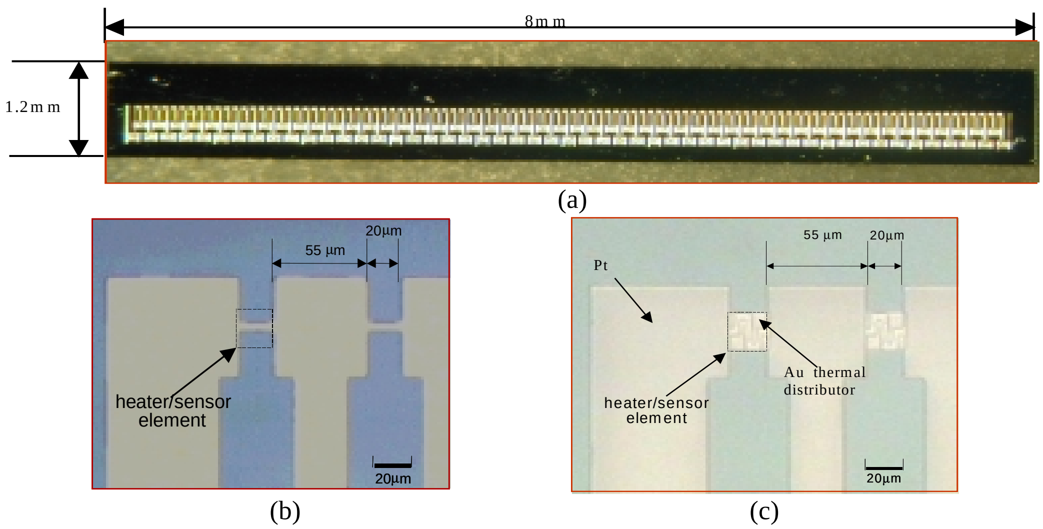

Fig. 1 One dimensional Pt heater/sensor array (a) 100 pixel array (b) close view of straight pixel (c) close view of meander pixel

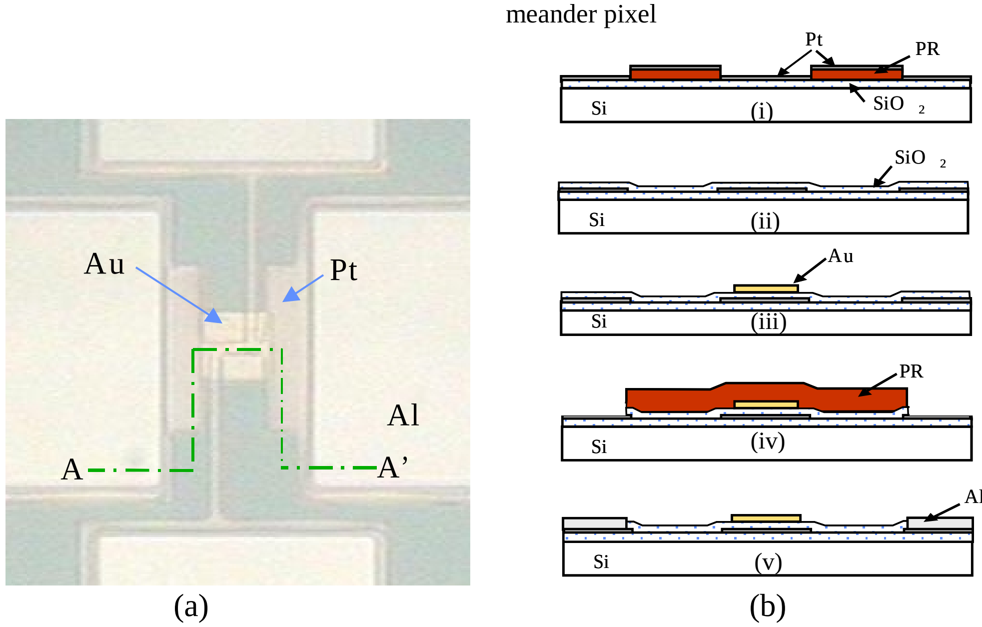

Fig. 2 Fabrication process (a) Single Pt heater/sensor top view (b) Fabrication Sequence in cross-section of A-A': (i) Photoresist spin coating (1mm) and Pt deposition (E-beam evaporation) on SiO2 (5000Å) (ii) Remove PR and Pt on PR (Lift-Off). SiO2 (4000Å) depostion(PECVD) (iii) Repeat Lift-Off for Au(2000Å) patterning (iv) PR spin coating and patterning for pad window opening. SiO_2 etching (v) Lift-Off for Al(3000Å) deposition on Pad and remove PR.

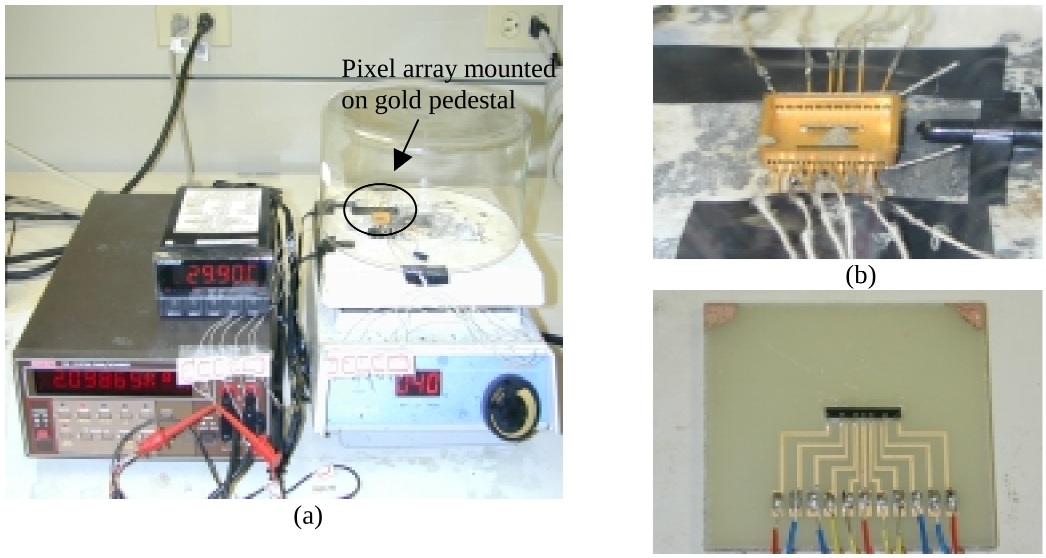

Fig. 3 Test setup of Pt resistive property according to temperature (a) overall setup (b) Pt array mounted on gold plate (c) Pt array mounted on PC board

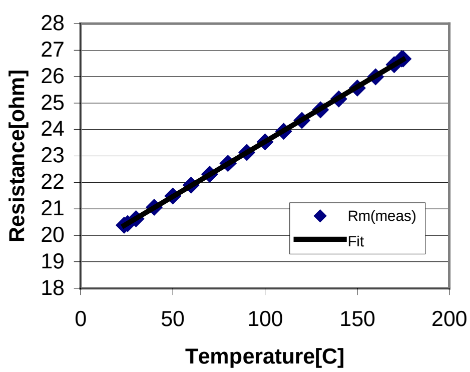

Fig. 4 Pt resistance according to temperature: R=0.0414T+192.57

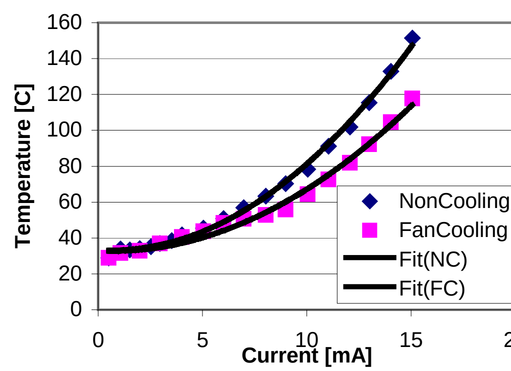

Fig. 5 Temperature according to applied current: diamond shows noncooling; square does overall fan cooling

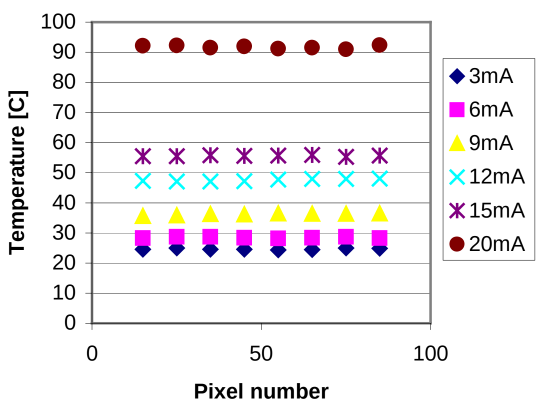

Fig. 6 Spatial temperature distribution through the pixel array

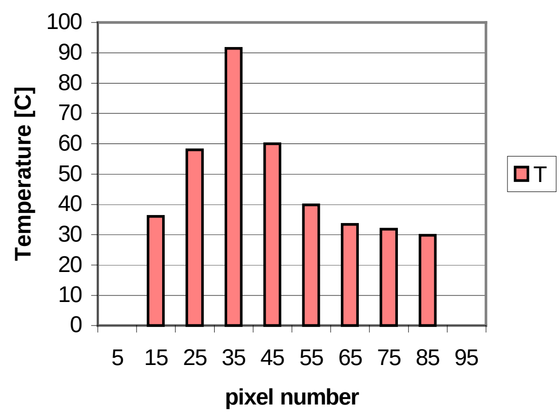

Fig. 7 Spatial temperature profile due to local heating