Microfabrication of Heaters and Resistance Thermal Detectors for Simulation of Hotspots

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Abstract:

A steady decrease in feature sizes and increase in transistor density has resulted in microprocessors with increased power density and non-uniform heat generation. This has led to the development of hotspots, whose elevated temperatures necessitate the application of localized cooling solutions. This project was concerned with the development of a cooling system (called Nanopatch) for hotspots, capable of dissipating high heat fluxes using evaporation of a thin liquid film. Specifically, devices consisting of a heater and sensor system were fabricated to test the operation of the Nanopatch. Each device consisted of a central hotspot heater surrounded by multiple sensors, fabricated on a Pyrex® substrate using metal deposition and lift-off techniques. The sensors were resistance temperature detectors that, after temperature calibration, can be used to provide an accurate thermal map of the substrate while the central heater is activated.

Introduction:

Advances in semiconductor technologies are leading to the creation of more powerful microprocessors with decreasing transistor sizes and higher power density. Furthermore, the clustering of transistors results in significant spatial variations in temperature across the chip, leading to the development of hotspots, which can be damaging to microprocessor performance. Traditional cooling systems, consisting of a heat sink and a fan, are ineffective at dealing with hotspot cooling due to their large size. A more efficient, localized cooling mechanism that can be integrated with background cooling is necessary in order to manage hotspot temperatures.

Phase change heat transfer is more advantageous for dissipating hotspot heat fluxes than single phase convention cooling due to the high latent heat of vaporization. A solution to the hotspot cooling problem was proposed in the form of a Nanopatch that employs the evaporation of a thin liquid film through a porous membrane [1]. A heater and sensor system was designed in order to test the effectiveness of the Nanopatch. This device, containing a central hot spot heater and 35 resistance temperature detectors around it, allows distinguishing between the amount of heat dissipated by the cooling patch and that lost to the substrate and the ambient.

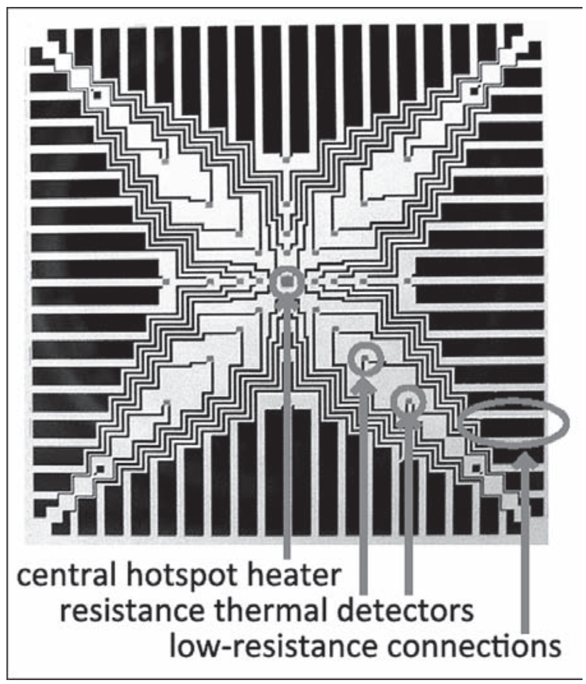

Figure 1: Diagram of heater and resistance thermal detector device.

Experimental Procedure:

The devices containing the heaters and resistance thermal detectors were designed as illustrated in Figure 1, and fabricated on a 4-inch Pyrex wafer. All sensors had 250 μm side lengths, while the heaters were of three different sizes (250, 500, and 750 μm). An illustration of the process for an individual sensor is in Figure 2. The first step consisted of laying down a layer of platinum to create the heaters, sensors, and connections. This was done using a typical photolithography process, followed by electron beam evaporation of 300 nm of platinum (along with a thin layer of titanium for adhesion), and a lift-off process. The second step consisted of adding copper and gold—metals with lower resistivity—on top of all the connections. This was done with an analogous process of photolithography with adjusted baking times due to the partial conductance of the substrate, followed by deposition and lift-off of 300 nm of copper and 200 nm of gold (Figure 3).

Once the metal pattern was formed, a 0.5 μm layer of silicon dioxide was deposited, and a third photolithography process was done to expose the ends of the connections along the perimeter of the device. At these ends, the silicon dioxide was etched through to the gold layer, in order to enable wire-bonding between the device and the printed circuit board (PCB). A multi-meter was used to check for electrical connectivity to ensure the completion of the etching process.

Results and Conclusions:

One successfully fabricated device was set up for temperature calibration. A copper block with an embedded cartridge heater was placed inside an insulated enclosure. A fan was used to ensure uniform heating of surrounding air. While the copper block was heated using a variac, air temperature was monitored using three thermocouples at different locations inside the enclosure. The resistances of 16 sensors were monitored using a data acquisition system while the copper block was continuously heated with varying power. The resistances were recorded every 30 seconds as the temperature was raised from 25 to 80°C.

Combining temperature data from the thermocouple closest to the substrate with the resistance data, a calibration curve for each sensor was created, graphing the temperature of the sensor as a function of its resistance (Figure 4). The equation of a linear fit is used to calculate temperature at that sensor from any measured resistance value. Thus, the fabricated device will be used to test the effectiveness of the cooling Nanopatch by providing a thermal map of the substrate when the central heater is in operation and the patch is applied to hotspots of different sizes.

Future Work:

An addition to present work could be the inclusion of a background heating capability in order to completely mimic a microprocessor's heat generation. This could be done with an additional photolithography step on the back side of the substrate, followed by metal evaporation and lift-off. Silicon rather than Pyrex would be used in order to enable efficient heat transfer through the substrate.

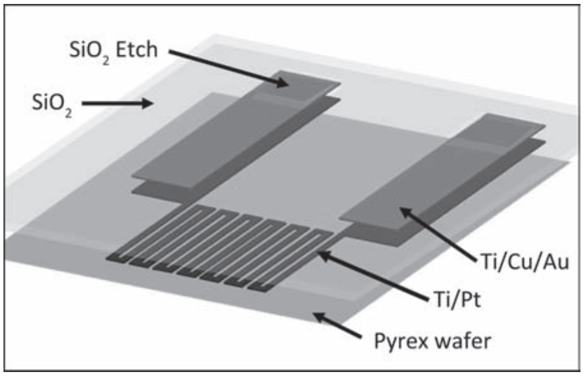

Figure 2: Fabrication layers for an individual sensor with connections.

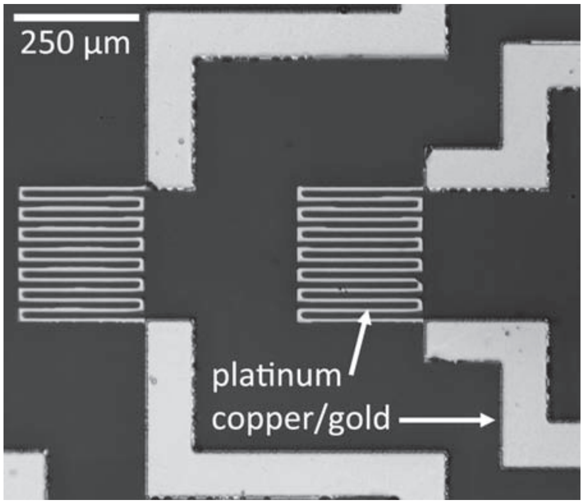

Figure 3: Microscope image of two sensors after Cu/Au deposition and lift-off.

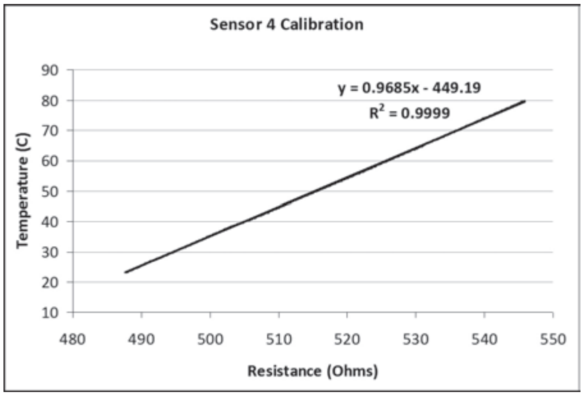

Figure 4: Calibration curve for one of the sensors.

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References:

[1] S. Narayanan, A. G. Fedorov, Y. K. Joshi, "Gas-Assisted Thin-Film Evaporation from Confined Spaces for Dissipation of High Heat Fluxes," Nanoscale and Microscale Thermophysical Engineering, 13: 30-53, 2009.