MONITORING THE RESTORATION OF INTERFACIAL CONTACT FOR SELF HEALING THERMAL INTERFACE MATERIALS FOR LED AND MICROELECTRONIC APPLICATIONS

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ABSTRACT

While conventional self healing materials focus on the restoration of mechanical properties, newer generations of self healing materials focus on the restoration of other functional (i.e. non-mechanical) properties. Thermal conductivity is an example of an important functional property of a Thermal Interface Material (TIM) for LED's and microelectronics devices. Current TIMs are optimized to provide thermal conductivity for as long a time as possible, yet these materials have no self healing potential and any crack formed will only lead to a decreased or lack of thermal conductivity and will dramatically reduce life time of the component.

In order to get a better insight on how, as function of time, self-healing TIM systems are able to recover structural (cracks) and interfacial (delamination, adhesion) damages, we have developed a new specific technique to monitor local heat conduction. This technique probes very locally the heat transfer through the material to monitor changes related to heat conduction. If the material is damaged (cracked), the cracking or delamination will result in a thermal impedance restricting the thermal transfer. If the material is self healing, the local thermal conduction paths will be restored in time. In order to probe the thermal transfer for conventional and our new self healing TIM materials, a dedicated silicon chip containing an array of 49 diodes spaced uniformly over a 1 cm^2 area has been fabricated. Using this device, it is possible to map with high spatial resolution the efficiency of the local thermal transfer and to relate it to the recovery of pre-imposed damage.

Such experiments will yield unique local and temporal insight into cohesion and adhesion recovery of our self-healing polymeric systems.

1. INTRODUCTION

Since the development of self-healing materials, some effort has been made to develop new characterisation techniques that lead to a quantification of a self healing response. The quantification of the recovery of the mechanical properties has been studied for many materials and is well established. However, the self healing concept also involve material able to recover other functionalities. Self-healing composites having the ability to recover their adhesion, cohesion and thermal conduction properties have been recently produced in our group [1, 2]. These new types of material have potential application as thermal interface materials (TIM) for micro- and opto-electronic application. Failure of TIM usually involve bulk voiding, interfacial voiding or delamination and erosion [3]. These failures are non-reversible and always lead to a dramatic decrease of the overall system reliability or catastrophic failure. In this respect the use of a self-healing material as TIM will allow an increase in the system reliability and product life time in general [4]. There are several methods that are commonly used to characterize the performance of TIMs [5]. However none of them are suitable to *in-situ* characterize a recovery of property loss. In our study we are interested to quantify and investigate the effect of a multifunctional self healing composite on the recovery of interfacial thermal transfer. For this purpose a specific device has been developed that will allow us to monitor and quantify the recovery of thermal transfer as function of the "healing" of interfacial damages.

2. MATERIALS

In order to investigate the restoration of interfacial thermal transfer, a specific microelectronic device has been developed. This device consist of an array of 7*7 diodes on a 1 cm^2 silicon chip. The device dimensions are 1*2 cm^2 (W*L). The diodes use one common anode and each diode need its own cathode. In this configuration, 50 connections need to fan-out from the actual test area and be soldered on a print circuit board (PCB) for practical reasons. During the measurement, each diode will be connected to a current-voltage (IV) analyser via a multiplexer (Figure 1).

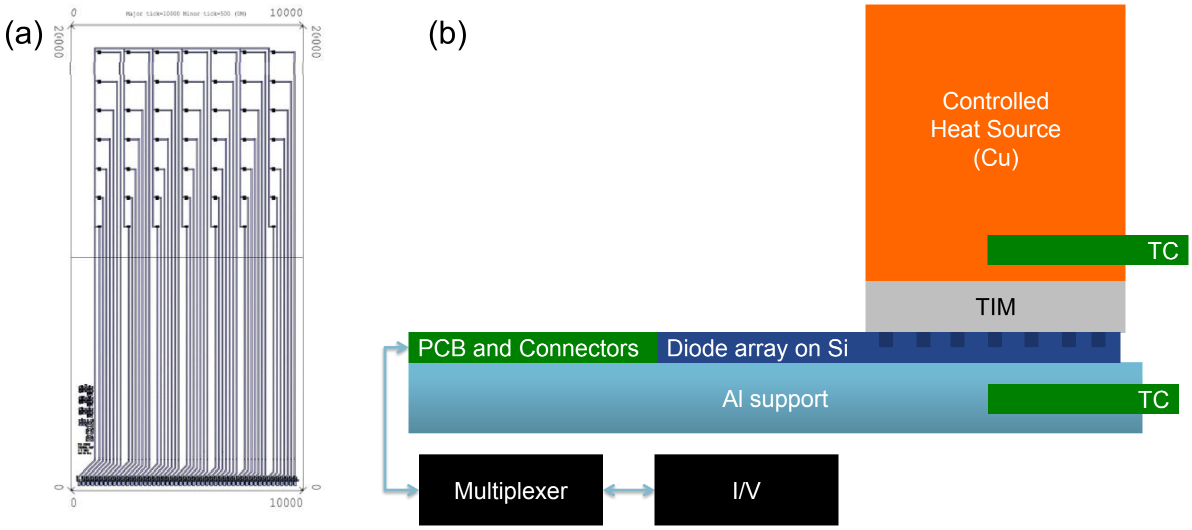

Figure 1: (a) Diode array with all connection and (b) measurement scheme including the controlled heat source, the self-healing material to be investigated (TIM) and the Si based sensor.

3. METHODS

The forward biased current through a silicon p-n junction is exponentially dependent on the temperature (equation 1). Hence the diode can be used as a thermo sensor and using micro electronic manufacturing technologies, large array of spatially small sensors are straightforward to fabricate.

$$I = I_0\left(e^{\frac{V}{nkT}} - 1\right) \tag{1}$$

$$\ln\left(\frac{I}{I_0}\right) = \frac{V}{nkT} \tag{2}$$

The logarithmic current-voltage plot of a diode is presented in Figure 2a. There are three main regions:

- at low forward bias voltage the current is related to the charge carrier recombination in the depletion region resulting in n>1 (theoretically n=2).
- a linear response at medium forward bias voltage. This is the so-called ideal region where the current is dominated by the diffusion of charge carriers over the p-n junction.
- a region where electrical resistance and high injection effects becomes dominant.

The voltage ranges at which the different regions can be identified is dependent on the diode area and the technology used to fabricate the diodes. To measure the temperature several strategies exist and need calibration step [6]. The chosen method do not require a calibration. Indeed, at medium forward bias voltages, the slope of a logarithmic current-voltage response is inverse proportional to the temperature (equation 2). Hence the temperature can be extracted from a current measurement at 2 different bias voltages. Particularly for large diode arrays, a no-calibration strategy is an advantage and can be applied if a common ideal region is found for all the diodes in the array.

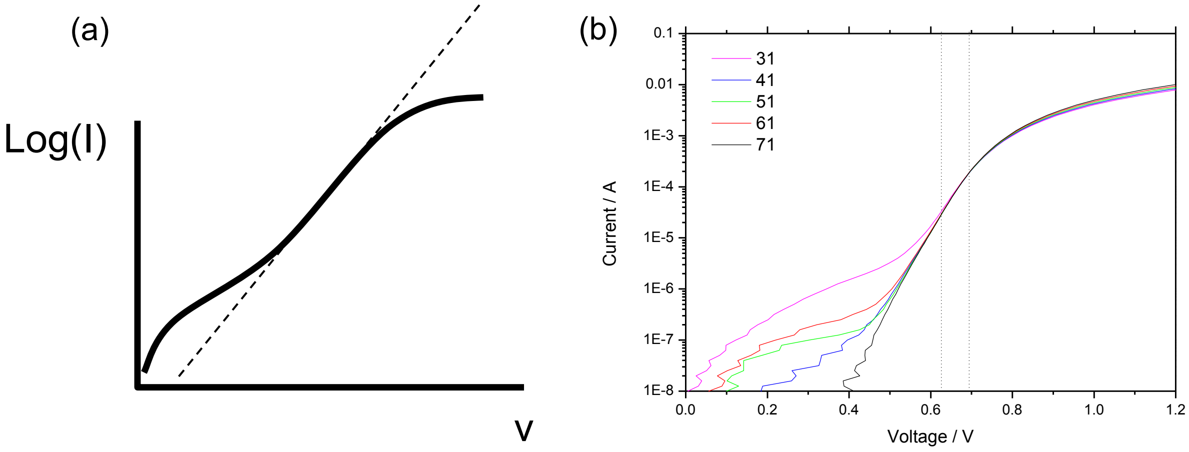

Figure 2: (a) Ideal Logarithmic IV response of a silicon diode showing the linear response. (b) IV response of several diode of the array measured at room temperature.

As each of the diodes in the array will act as singular thermal sensor, the changes in the temperature at the interface will be monitored as function of the position and as function of time. In comparison to an intact interface between the TIM and the diode array, interfacial damages will lead to a delay in thermal transfer. The recovery of the interfacial contact due to the self-healing ability of the TIM material use will be monitored in terms of temperature changes as function of time, i.e. as change in the delay time.

4. RESULTS

First, the IV response of the fabricated diode array has been investigated to look at the individual behaviour of each diodes. As it can be seen on Figure 2b, all diodes exhibit a linear response window that will be used for the temperature measurement. At 25°C the slope of the logarithmic response of each diode is equal to 0.001. For the temperature measurements, a forward bias voltage between 0.6 and 0.7 V will be used as it fit the linear voltage response region. Actual interfacial recovery results will be presented at the conference.

5. CONCLUSIONS

The use of silicon diode array in an integrated circuit configuration is a suitable strategy to construct a 2D heat-flow sensor. Besides having the ability to determine experimentally and in-situ the heat flow through a thermal interface material, it will be possible, in case of using a material with self-healing ability, to characterise the heat flow recovery after damage such as void or delamination. Finally, the direct correlation between the heat flow recovery and the interface or bulk healing of the thermal path can be translated in term of material healing efficiency.

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