AN IN-SITU END-POINT DETECTOR FOR PARYLENE CVD DEPOSITION

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ABSTRACT

We present the results of the development of an in situ end-point detector for a Parylene chemical vapor deposition process. The detector is based on the thermal transfer principle and can be implemented on commercial Parylene deposition systems with minimal system modification. Such a sensor enables a user to stop the deposition when a targeted thickness is reached. The end point detector is very simple to implement on existing Parylene deposition systems. A series of such sensors with different target deposition thickness would allow extraction of the actual deposition rate within a deposition run.

BACKGROUND

The chemical vapor deposition process of Parylene (poly-para-xylylene) is well established [1]. Parylene is a dielectric polymer material that may be grown by chemical vapor deposition methods at room temperature. It is an exceptionally conformal coating material with very low pinhole density. The intrinsic stress of Parylene is relatively low compared with that of silicon oxide and silicon nitride. Due to its unique ability to seal and encapsulate [2], the material is useful for telecommunication devices, integrated semiconductor devices, micromachining, and document preservation, etc. In recent years, Parylene has been used to fabricate microelectromechanical devices such as microfluidic circuits [3,4], micro-injectors [5], and valves/pumps [6], to name a few. Since the film is used to function as a mechanical structure, the thickness becomes an important parameter that determines the performance specifications of sensors and actuators.

At present, it is difficult to predict and control the deposition thickness. The method for controlling the thickness is to preload the deposition system with a controlled amount of dimer material. The

classified as the complete sublimation of all dimer material. One major manufacturer of Parylene deposition systems predicts that final Parylene thickness can be controlled to within +/-10% of desired thickness using this method. This degree of accuracy may not be satisfactory for many MEMS applications, however. Actual experimental data gathered at our laboratory demonstrates that the Parylene thickness exhibits even greater run-to-run variance than the manufacturer suggests. The inaccuracy of predicting and controlling the deposition thickness is especially problematic when the deposition thickness is small (e.g., less than 5 µm). It is even more difficult to predict the duration of a process run with same amount of dimer.

SENSOR PRINCIPLE

We have developed an in situ end-point detector for accurately monitoring the deposition thickness of Parylene. The sensor (Figure 1) consists of a heating element and a temperature sensor. The heater and the temperature sensor are located at distal ends of two diving-board-type cantilever beams. The distance between the distal ends of the two cantilever beams, denoted d, is well defined using photolithography.

Figure 1: Schematic diagram of the end-point sensor.
The heater, made of thin-film metal coil, generates ohmic heating when an electrical current passes through. Parylene is deposited in a low-pressure environment, with the typical deposition pressure ranging from 20 to 40 mtorr. When a sensor with an open gap is placed in a vacuum, the thermal conduction through the gap is negligible.

As Parylene is deposited in a conformal fashion, the distance between the two distal ends of cantilevers is gradually reduced (Figure 2a). When the Parylene thickness reaches \(d/2\), the two Parylene fronts will meet, thereby filling the gap and completing a thermal conduction path (Figure 2b). As the gap is filled with Parylene, a thermally conducting medium, heat can be transferred via a “thermal short-cut” to reach the temperature sensor. This change of thermal transfer characteristic (both transit time and amount of heat transfer) can be used to infer the process end point. A single sensor with a gap \(d\) can indicate when the Parylene thickness reaches \(d/2\).

**DESIGN AND FABRICATION**

The configuration of a typical sensor is shown in Figure 3. Generally speaking, it is advantageous to use thin and narrow beams in order to increase the thermal resistances. However, metal coils (heater) and associated wire leads exhibit intrinsic stress, which may bend the supporting cantilever beams. The bending could become significant compared to the gap spacing \(d\) if the silicon beam is overly thin. This would alter the effective distances between the heater and sensor. In our studies, space distortion has been found in samples with the cantilever beam thickness being less than 8 \(\mu m\). On the other hand, if the beams are overly thick, the heat transfer associated with the heater and temperature sensor will be reduced. The device would require more power to operate.

To avoid distortion of gap spacing due to intrinsic stress, we use single crystal silicon for the cantilever beams. Single crystal silicon material has very little intrinsic stress. The thickness of the beams is carefully controlled in process. The thickness of the cantilever beams is 40 \(\mu m\). The value of the effective thermal resistances associated with the temperature sensor and the heater are \(1.3 \times 10^7 W/K\), assuming that the thermal conductivity of silicon is 149 \(W/m \cdot K\).

The sensor fabrication process is described as follows. Starting with a <100>-oriented silicon wafer, we grow thin thermal oxide as a mask for doping. We then perform selective doping to form the silicon thermistor. Thin-film metal (200-nm-thick gold) is evaporated and patterned to form heating resistors. Bulk etch is performed from the backside of the wafer, using either deep reactive ion etching (DRIE) or anisotropic silicon etching. The wafer is etched to a predetermined depth. The thickness of the resultant single-crystal silicon membrane is controlled by timed etch. This is followed by reactive ion etching from the front side to define the cantilever beam. The heater and the temperature sensors are located at distal ends of two cantilever beams.

The scanning electron micrograph of the gap between the heater and the sensor for a typical device is shown in Figure 4.

**SENSOR CHARACTERIZATION**

**Preparation**

We have experimentally proven that, if power is applied to the heater for an extended period of time, the substrate of the sensor will be heated to a higher temperature. It is shown that the time constants associated with the heating and cooling processes are 336.8 s and 145 s, respectively. The temperature difference between the unheated and...
the heated case is 16.9 °C, based on the known TCR value.

Incidentally, we discovered that the thickness of the deposited Parylene is much lower if the chip substrate is at a constant elevated temperature. The power to the heater must be provided in short pulses to interrogate the sensor. This would avoid significantly raising the temperature of the substrate.

Figure 4: SEM micrograph of (a) the gap between the temperature sensor and the heater; (b) four pairs of heater/temperature sensor with varying gap sizes.

Measurement Setup

We applied the sensor to a commercially available PDS 2010 Labcoter® 2 deposition system. Because the system is not equipped with vacuum-sealed electrical access wires, we have modified the observation window to provide electrical access. The observation window, made of glass or plexiglass, can be removed easily from the vacuum dome. Holes are drilled in a replacement window to allow wire leads to pass through. The holes are then sealed using an epoxy material. A sensor chip is located inside the vacuum dome using a machined rack. The power supply and ohmmeter are located outside the vacuum dome. A computer provides long-term direct data acquisition (at 0.5 s intervals) from the ohmmeter through an RS-232 link.

End-Point Sensing

We monitor the resistance of the temperature sensor throughout courses of deposition runs by applying square-wave pulses with a constant magnitude (5 V) and pulse width (5 s). The average interval between pulses is 5 min. We believe that this brief heating does not cause sufficient substrate heating to disrupt the thickness of the local Parylene deposition. The resistance output of the sensor during a typical run is shown in Figure 5. The thickness of the deposited Parylene material is independently verified by measuring the Parylene thickness on companion wafers using surface profilometry. A section of Parylene film is manually peeled off. A surface scan is conducted across the edge of the tear.

During a typical run that lasted 1 h, 15 peaks are registered, corresponding the application of 15 power pulses. The general appearance of the first ten peaks is different from that of last five peaks. We conjectured that the appearance indicates whether the gap has been bridged. A typical waveform selected out of the first ten peaks is shown in Figure 6. As the power is suddenly increased, the resistance (and therefore temperature) of the sensor increases exponentially with a measured time constant on the order of hundreds of seconds. After the power is cut off, the resistance value gradually returns to the original level.

A representative plot of the last five peaks is shown in Figure 7. It is obvious that the resistance of the temperature sensor changes rapidly upon application of the power. This rapid change is caused solely by the fact that the heat pulse travels directly across the gap, now bridged by Parylene, to the temperature sensor. The rate of resistance change then slows, indicating that the substrate heating effect has taken over. After the power is turned off, it is again seen that the resistance decreases rapidly before the substrate heating effect catches up.

Figure 5: Response obtained in real time during a run that lasted 1 hour 17 min. The signal strength increases visibly after roughly 57 min. The sensor is interrogated every 5 min after 25 min into the process.
Figure 6: Rise and fall of resistance under a step power input to the heater. This is obtained before the gap is sealed.

Figure 7: Rise and fall of resistance under a step power input to the heater. This is obtained after the gap is sealed.

We performed 12 Parylene deposition runs using 12 sensors with different gap spacing ($d/2 = 0.5$, 1, 2, 2.5, and 5 µm). The actual measured thickness is plotted against the target thickness (Figure 8). The inaccuracy of data can derive from many sources, including inexperience of using the sensor at this point, as well as random and systematic sensor errors (e.g., gap size variation). We believe the accuracy will further improve with greater number of runs and more expertise in using the sensor. Nonetheless, the effectiveness of the end point sensor is clearly illustrated.

CONCLUSIONS

An end-of-process monitor for Parylene deposition has been designed, fabricated, and tested. The sensor, based on thermal transfer principles, consists of a heater and a temperature sensor separated by a well-defined gap, $d$. When the Parylene deposition reaches $d/2$, the heat can conduct through the gap, in addition to conduction through the substrate. The thermal signature is used to determine the gap-closing event. We have found that the end point can be identified by the time constant of the heating and cooling process. Preliminary results of thickness control have been obtained.

Figure 8: Results of 12 deposition runs using sensors with five target thickness ($d/2 = 0.5$, 1, 2, 2.5 and 5 µm).

REFERENCES