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곽기영, 이명진, 김재성, 강문식, 민남기
고려대학교

A Locally Cured Polyimied-based Humidity Sensor with High Sensitivity and High Speed

Ki-Young Kwak, Myung Jin Lee, Jae Sung Kim, Moon-Sik Kang, Nam-Ki Min
Korea University

Abstract - Polyimide thin films were cured locally using MEMS microhotplates. The polyimide locally cured at temperature over 350℃ for 1 hour was fully cured. There was no significant difference between polyimide thin films cured in a conventional convection oven and those cured locally on MEMS microhotplates. The locally cured polyimide humidity sensor showed a linearity of 0.9995, a sensitivity of 0.77 pF/%RH, a hysteresis of 0.6 %RH, and a response time of 3s. These results indicate that the locally-cured polyimide films may be used as dielectric material of high speed, high-sensitivity humidity sensors.

1. INTRODUCTION

Polyimide thin films are used as a dielectric material in capacitive humidity sensors since they provide high sensitivity, a linear response to humidity, low power consumption, and good thermal stability [1-3]. Polyimide is typically solvent cast onto the desired substrate and then thermally cured as a thin film in convection ovens at temperatures between 300°C - 400°C depending on the application. This high temperature can affect the electrical properties of the devices, especially in case of CMOS-based sensor because the maximum temperature acceptable for CMOS circuits or other sensors does not match with the curing temperature of polyimide film. If these films were cured on the wafer or sensor chip, locally rather than globally, there could be a minimization of effect on the device as well as a lower thermal budget. The goal is to replace the global, conventional cure process with a localized cure process in polyimide humidity sensor applications, and to enhance the sensitivity and speed.

2. EXPERIMENTS

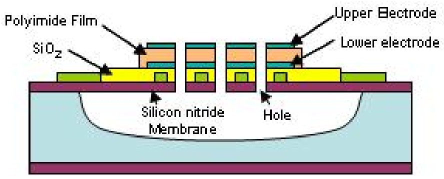
2.1 Fabrication of Microhotplate

The microhotplates were fabricated on n-type, (100)-oriented silicon wafers. Each microplete consists of a silicon nitride membrane that has embedded Pt heater and Pt RTD (Resistance Temperature Detector) thermometer which is used to measure the temperature on the MEMS microhotplate.

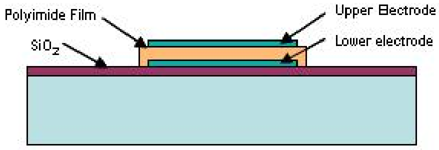
The microhotplate fabrication process starts with the LPCVD deposition of an 8000 Å thick, low-stress silicon nitride layers to be used as a supporting membrane for the devices. For microheater and RTD, 2000Å/200Å thick Pt/Ta layers are then deposited on the supporting silicon nitride layer and patterned by a lift-off process with optical lithography using negative tone photoresist.

2.2 Fabrication of Humidity Sensors

As shown in Figure 1, two different humidity sensors (Design A and Design B) have been fabricated. The patterned heater and RTD were covered with a 5000 Å thick CVD oxide. After spin-coating and curing polyimide films, porous Cr film was deposited on some polyimide thin films and patterned using photolithography to form the upper electrode of the conventional humidity-sensitive capacitors. The response time of a humidity sensor can be enhanced by modifying the shape and dimensions of the polyimide film [4]. To enhance the response speed the micro-bridge structure with a lot of holes was created using front-side etching with XeF_2 gas, as shown in Figure 1 (a). This procedure undercuts the film to create suspended Si_3N_4 membrane structure.



(a) Design A

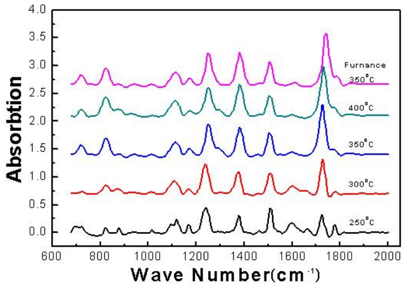


(b) Design B

<Fig.1> Schematics of two capacitive humidity sensors fabricated (a) on a microhotplate and (b) on a silicon substrate.

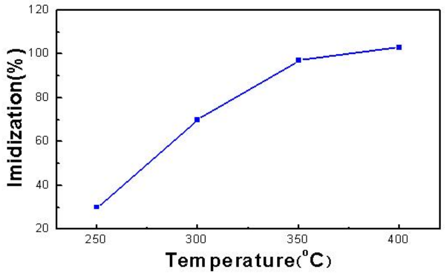
3. RESULTS

The locally cured polyimide films have been characterized using infrared spectroscopy and compared to those of films cured using a conventional thermal process. Figure 2 shows the FTIR spectra for a microhotplate cured polyimide film used to calculate the extent of imidization. The 1380 cm^{-1} peak can be used as an indication of degree of cure[5]. This peak is observed when the imide ring closes. The 1500 cm^{-1} peak does not change during cure and can be used as an internal reference peak.



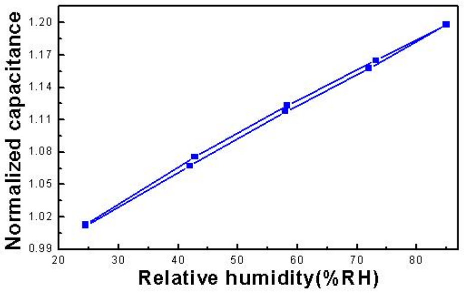
<Fig.2> FTIR spectra for locally cured polyimide films.

Figure 3 shows the degree of imidization calculated from Figure 2, based on the peak are as of the 1350 and 1500cm^{-1}bands. The polyimide locally cured at temperatures over 350°C for 1 hour was fully cured. The polyimide locally cured at temperatures over 350°C for 1 hour was fully cured. Within the accuracy of FTIR, there are no detectable differences in the polyimide thin films between cured in convection ovens and locally cured on microhotplate. However, a level of 75% imidization was achieved at 300°C for 1 hour.

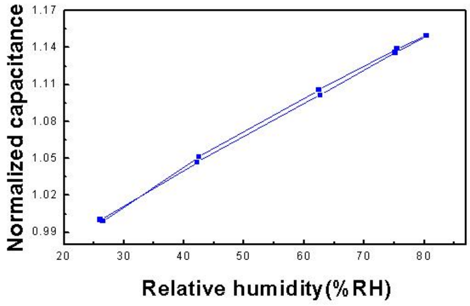


<Fig.3> Degree of imidization as a function of cure temperature.

Figure 4 shows a normalized capacitance versus relative humidity for a locally-cured polyimide humidity sensor (Design A). The capacitance was measured using a LCR meter at 20 kHz, 1 V_{rms} in an environmental chamber. The locally cured devices showed a sensitivity of 0.77pF/%RH, a linearity of 0.9995, and a hysteresis of 0.6%RH. The response time was measured to the 90%-point of the final steady-state capacitance value, after an abrupt change in the ambient relative humidity level.



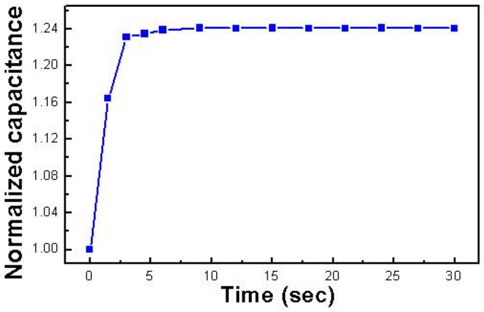
(a) Design A



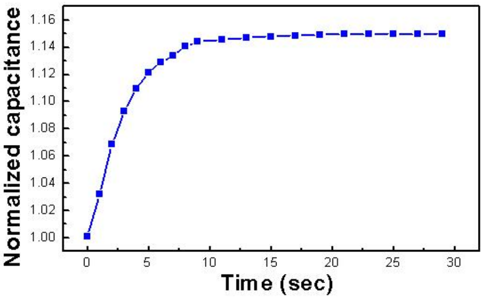
(b) Design B

<Fig.4> Normalized capacitance versus relative humidity for a locally-cured polyimide humidity sensor.

Figures5 (a) and (b) show the dynamic response waveforms to an abrupt humidity change. The response time constant associated with the polyimide humidity sensor with high speed structure (Design A) is about 3s, while Design B has a time response of 7s. In Design B device, moisture diffusion takes place through the porous upper electrode only. In contrast, a Design A device has many holes and moisture is thus absorbed into the top and side surfaces of polyimide because the sensing film is more exposed to the environment.



(a) Design A



(b) Design B

<Fig.5> Response of the locally cured device to an abrupt humidity change in ambient relative humidity from 30 to 80%RH at room temperature.

4. CONCLUSIONS

A high-speed capacitive humidity sensor was achieved by introducing a micro-bridge structure created using the front-side etching with XeF_2 gas and allowing moisture to diffuse into both top and side surfaces of polyimide film. Spin-coated polyimide films are successfully cured using an indivisual MEMS microhotplate. This method opens up new possibilities of employing individually controllable polyimide thin film fabrication that was not available in conventional wafer-scale curing process using convection ovens. A localized curing of polyimide film protects components or electronics on the same chip, from excessive heating which now can be applied locally only at the selected microhotplates.. These results indicate the feasibility of locally-cured polyimide film for a high speed, high-sensitivity capacitive humidity sensor applications.

ACKNOWLEDGMENTS

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