Study of polymer humidity sensor array on silicon wafer

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Polymers as humidity-sensing materials possess many advantages such as high sensitivity, low cost, simple fabrication technique, and wide choices of molecular structures for improving their properties [1–6]. Most of the resistive-type polymer humidity sensors are fabricated by synthesizing the polymer films on a ceramic substrate [6–9]. Ceramic alumina has good thermal and chemical stabilities, so it is suitable as a substrate material for humidity sensors. However, it is very difficult to integrate many sensors and control systems on a ceramic substrate. It is desirable to fabricate humidity sensing films on silicon substrates since silicon possesses good electrical and mechanical properties and is a very good material for integrated circuits (IC). Recently, some papers reported results of fabricating inorganic sensing films on Si or SiO_2/Si substrates [9–13].

In this paper, we report the sensing properties of the humidity sensor array made of the polymer material quaternary acrylic resin (RMX) films on silicon substrate, including the sensitivity, hysteresis, response, and recovery times. Also analyzed are the properties of impedance and capacitance versus relative humidity (RH) at different frequencies.

Four sets of interdigital-type gold electrodes are made on a silicon wafer using IC plant techniques. Fig. 1 shows a photo of the silicon substrate of the sensor array. The area of the silicon wafer is 9×8 mm^2. The electrode gap is 0.1 mm.

The polymer RMX is a kind of electrolytic organic humidity-sensing material, where R denotes the carbonic long chain of the polymer and M and X represent anode ion NH_3^+ and cathode ion Cl^-, respectively. Its structure is as follows:

$$
\begin{array}{cc}
-(\mathrm{R})_m- & (\mathrm{R})_n- \\
| & | \\
\mathrm{R_1OOC} & \mathrm{COOR_2M^+X^-}
\end{array}
$$

The preparation of polymer quaternary acrylic resin is reported in [14]. Put a 0.1-g polymer RMX into 10^{-6} m^3 alcohol and disturb it to form a homogeneous gel. The polymer films are formed on the silicon wafer by dip-coating method. The area of the film of each humidity sensor is about 12 mm^2. The thickness of the film is about 10 μm. Resistive-type humidity sensors of polymer films are made after baking them at 70 °C for 30 min and aged them at 100% RH with a voltage of a.c. 1 V for 24 h.

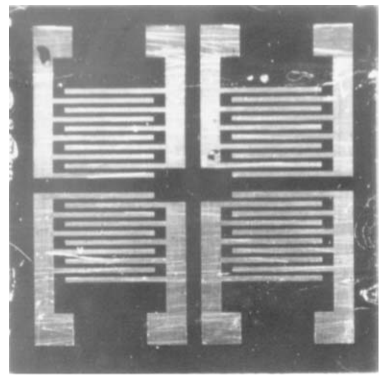

Figure 1 Photo of the silicon substrate of the humidity sensor array.

The resistance, capacitance, and impedance of the sensor are measured by putting it successively into several chambers with different RH levels obtained using saturated salt solutions. The measuring equipment is ZL5 LCR intelligent test meter (Shanghai, China). The frequency ranges from 10 Hz to 100 kHz, and RH varies from 11 to 98% under the temperature about 15 °C.

Fig. 2 gives the resistance against RH of the polymer RMX/Si sensor. The measurement voltage is a.c.1 V and the frequency is 100 Hz. The solid line in the figure is measured from low to high RH which is an adsorption process, and the dashed line is measured in the opposite direction as a desorption process. We can see that the resistance changes from 10^6 to 10^3 Ω when the relative humidity range is 11–98% RH, and that the sensitivity of the sensor (the slope of the line) is high. The maximum humidity hysteresis is 1–2% RH.

The response and recovery characteristics of the RMX/Si film humidity sensor are shown in Fig. 3. The response time of the adsorption process (as humidity changes from 33 to 98% RH) is about 12 s, and the recovery time of the desorption process (98–33% RH) is about 120 s.

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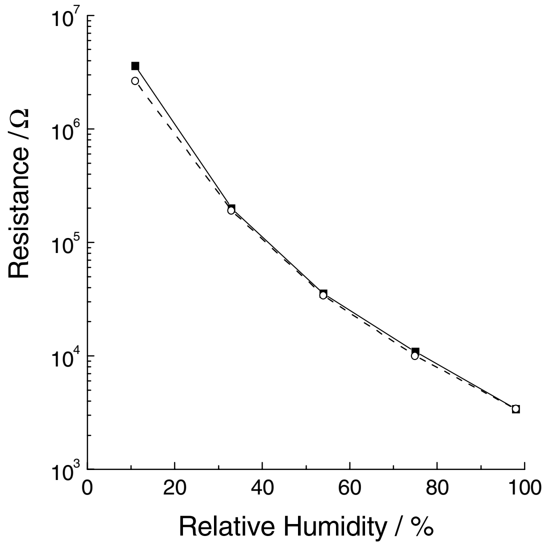

Figure 2 Resistance against RH of RMX/Si sensor.

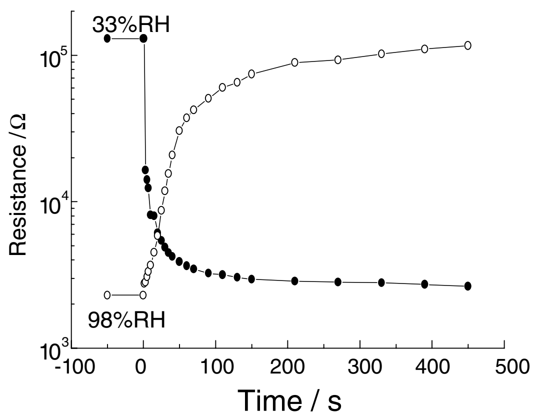

Figure 3 Response and recover properties of RMX/Si sensor.

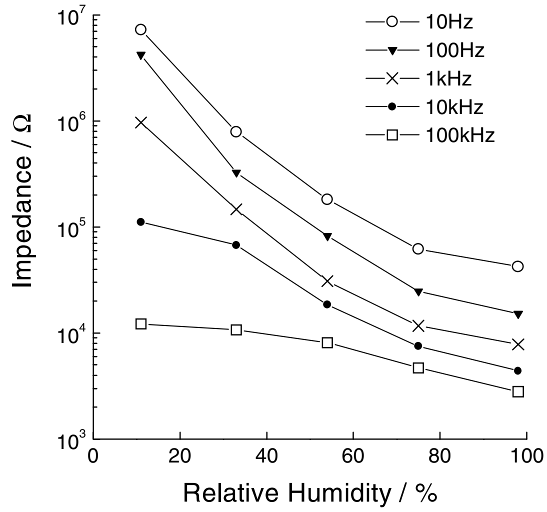

Figure 4 Properties of impedance versus RH at different frequencies.

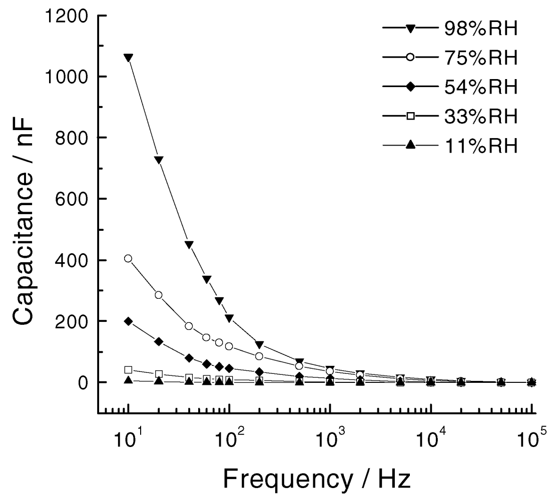

Figure 5 Plots of capacitance versus frequency at different RH.

The measured frequency obviously influences the impedance properties of the humidity sensor. Fig. 4 gives the plot of the impedance (Z) versus RH of the RMX/Si sensor with a voltage of 1 V and different measured frequencies. We can see that the impedance decreases as the frequency increases, and the best linearity of the Z–RH curve appears at the frequencies between 100 Hz and 1 kHz. The measured voltage hardly influences the sensing properties of the sensor. The curves of the capacitance of the sensor versus frequency at different RH are shown in Fig. 5. The capacitance hardly changes in the high-frequency range, and increases with RH in the low-frequency range, especially in high RH. The capacitance property represents the dielectric property of the materials. The electrical field direction changes slowly when the frequency is low, and the adsorbed water molecules will display space-charge polarization. The higher the RH is and the more the water molecules are adsorbed, the stronger the polarization is the larger the dielectric constant (capacitance) is. When the frequency is high, the electrical field direction changes rapidly, the polarization of the adsorbed water cannot keep up with it, and hence the dielectric constant is small and independent of RH.

The measured voltage level does not influence the sensing properties of the sensor in the voltage range of 0.1–1.2 V.

The polymer quaternary acrylic resin films are dip-coated on silicon substrate to make a resistive-type humidity sensor array. The sensor possesses good sensitivity, and the maximum humidity hysteresis is about 1–2% RH in the 11–98% RH. The response and recovery times of the sensor are 12 and 120 s, respectively.

The impedance versus RH curves is influenced strongly by the measured frequency. The best linearity of the Z–RH curve appears between the frequencies of 100 Hz and 1 kHz. The capacitance changes with the frequency and the RH, especially in the low-frequency range, which is due to the polarization of humidity sensing film occurring in low frequency.

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