Study on fabrication process of micro-bridge structure arrays based on amorphous silicon films

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In recent years, the development and application of uncooled infrared focal plane arrays technology have received more attention from internal and external researchers. All the thermal infrared detectors exhibit a change in some measurable properties that accompany a change in temperature of the sensitive element. The manifestation of the temperature increment depends on the detection mechanism. The thermal infrared detectors can be divided into three basic kinds: bolometer, pyroelectric sensors, and thermocouple[1,2]. The most common detection mechanism is the resistive bolometer.

Uncooled infrared focal plane arrays consist of a two-dimensional assembly resistive bolometer. Infrared radiation is absorbed by the sensitive material which causes the temperature of the material to increase. There are three heat transfer mechanisms, including conduction, convection, and radiation. Convection is not an important heat transfer mechanism in uncooled infrared focal plane arrays because it can be reduced by using the evacuated package. The heat loss via radiation cannot be reduced, so the heat loss via conduction should be avoided because the substrate can lose heat and the heat will transfer from one pixel to another[3]. Hence, the fabrication of the support structure is very important for the high-performance thermal detector arrays.

The structure has three functions which are mechanical support, thermal isolation, and an electrically conducting path. In the self-supporting micro-bridge structure based on amorphous silicon (a-Si) films, the a-Si film acts as both the supporting material and the thermal-sensitive material[4,5]. The basic process in fabricating this self-supporting structure relies on a surface micro-machining approach. Since it is not the standard surface process, it is very important to study the sacrificial layer technology. Therefore, the sacrificial layer technology is systematically researched, and a lot of key parameters are obtained in this letter.

The sacrificial layer technology is a key technology in micro-bridge structure fabrication. The thickness of the polyimide (PI) film determines the height of the micro-

bridge. If the contact hole can be etched by the developer during the first photolithography, the soft curing temperature and the choice of the dry etch rate determine the successful release of the sacrificial layer of the structure. In this study, PI (type PI-5, Institute of Polymer Materials in Shanghai Jiaotong University) was used as the sacrificial material.

The PI films were spun on the substrate after radio frequency plasma deposition (PECVD), it was patterned using inductively coupled plasma (ICP-98A, Institute of Microelectronics of CAS). The PI sacrificial layer was removed to form the a-Si self-supporting micro-bridge structure. Using the ICP-98A, the micro-bridge structure was made in the Institute of Microelectronics, Chinese Academy of Sciences with the following etching parameters: 120-sccm O₂ flow, 2-Pa working vacuum, 180-W radio frequency (RF) power, and 10-s etching time.

The procedure for fabricating the self-supporting micro-bridge based on the a-Si film is as follows. The PI films used as sacrificial layers were prepared by a spin coater, and the contact holes were etched using the developer. The a-Si films were then deposited by PECVD.

The critical technology for fabrication of the micro-bridge structure based on amorphous silicon (a-Si) films is studied. As a key technology in the fabrication of the micro-bridge structure, the sacrificial layer technology, including the preparation of polyimide thin films (i.e., curing, wet etching, and plasma etching processes), is systematically researched, and a series of key parameters are obtained. An improved process flow of self-supporting micro-bridge structure is established. Experimental results and scanning electron microscope (SEM) images show that the fabrication technology presented is simple and feasible. A 160×120 micro-bridge array is successfully fabricated using this method.

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and patterned by ICP-98A, and the sacrificial layers were finally released by the plasma etching process. The whole ten steps of the procedure are shown in Fig. 1.

After studying the sacrificial layer technology, better process parameters were chosen as follows: 1) The PI sacrificial layer was spun at a low speed of 800 r/min for 8 s, then a high speed of 2800 r/min for 60 s. Afterwards, it was softly cured using RTP-500 at 1-Pa pressure with 1800-s rising time and 160 °C processing temperature. Then, it was subjected to a holding time of 1800 s at ambient cooling. 2) The photoresist coating on PI was done at a low speed of 800 r/min for 8 s, then at a high speed of 2300 r/min for 30 s. It was pre-baked on a hot plate at 100 °C for 90 s. 3) It was exposed to ultraviolet (UV) light using the lithography machine (Q-4000, Quintel Corporation, USA) for 8 s, developed, and then wet etched for 65 s. 4) The PI was hard cured using RTP-500 with 1-Pa pressure, 30-min rising time, and 250 °C processing temperature. The ambient cooling involved 30-min holding time. 5) The low stress and high quality a-Si films were deposited by PECVD based on the following parameters: SiH$_4$10%/Ar90%, an 80-sccm flow rate, 67-Pa vacuum, 250 °C substrate temperature, a 30-W RF power, 6-min deposition time, and 200-nm film thickness. 6) Photoresist coating on a-Si films were done at a low speed of 500 r/min for 9 s, then at a high speed of 2300 r/min for 30 s. It was then pre-baked on a hot plate at 100 °C for 90 s. 7) It was exposed to UV using Q-4000 lithography machine for 8 s, developed, and wet etched for 65 s. 8) The a-Si film was patterned using ICP-98A at a gas flow rate of 120 sccm and 2-Pa working vacuum while using the SF$_6$ reactive gas with an RF power of 180 W for 10 s. 9) The sacrificial layers were released with a pressure of 2 Pa, 120-sccm O$_2$ flow rate, and 150-W RF power for 90 min. 10) The self-supporting micro-bridge structure based on a-Si films was finally fabricated.

The relationship between the film thickness and the spinning speed is shown as Fig. 2. The thickness of PI is primarily determined by the colloid viscosity and the spinning speed. However, the viscosity is constant, so the film thickness decreases with the increase of the spinning speed.

The thickness of the sacrificial layer is a key process parameter that directly determines the height of the micro-bridge structure. According to Fig. 2, the thickness can be obtained by adjusting the spinning speed.

The thickness of the sacrificial layer for the resonant absorbing cavity of the detector[7] can be obtained by

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**Fig. 1. Procedures of self-supporting micro-bridge based on a-Si film.**

**Fig. 2. Relationship between the film thickness and the spinning speed.**

**Fig. 3. SEM photos of the contact hole which is not etched completely with different soft curing temperatures. (a) 170 °C; and (b) 190 °C.**
Table 3. Relationship Between Plasma Etching Rate and Curing Temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Thickness before Etching (nm)</th>
<th>Thickness after Etching (nm)</th>
<th>Etching Time (s)</th>
<th>Etching Rate (nm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>2496.3</td>
<td>1737.8</td>
<td>3</td>
<td>252.8</td>
</tr>
<tr>
<td>150</td>
<td>2469.7</td>
<td>1774.1</td>
<td>3</td>
<td>231.9</td>
</tr>
<tr>
<td>160</td>
<td>2552.7</td>
<td>1860.9</td>
<td>3</td>
<td>230.6</td>
</tr>
<tr>
<td>170</td>
<td>2521.5</td>
<td>1871.1</td>
<td>3</td>
<td>216.8</td>
</tr>
<tr>
<td>180</td>
<td>2495.0</td>
<td>1788.1</td>
<td>3</td>
<td>235.6</td>
</tr>
<tr>
<td>190</td>
<td>2370.8</td>
<td>1735.8</td>
<td>3</td>
<td>211.7</td>
</tr>
<tr>
<td>200</td>
<td>2290.7</td>
<td>1548.8</td>
<td>3</td>
<td>217.7</td>
</tr>
<tr>
<td>210</td>
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<td>1564.8</td>
<td>3</td>
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<tr>
<td>220</td>
<td>2273.6</td>
<td>1670.1</td>
<td>3</td>
<td>201.2</td>
</tr>
</tbody>
</table>

Fig. 4. SEM photo of self-supporting micro-bridge structure.

Fig. 5. Cross-section SEM photo of self-supporting micro-bridge structure.

\[ d = \frac{\lambda_0}{4n}, \]

where \( n \) is the refractive index and \( n = 1 \) in vacuum, \( \lambda_0 \) is the infrared center wavelength and \( \lambda_0 = 8 \mu m \) in this uncooled infrared detector. As such, the thickness of PI is 2 \( \mu m \), and the spining speed is 3300 r/min.

It can be seen from Table 1 that the PI film thickness changes after curing. The shrinkage rate is about 20%, and it only slightly changes with temperature. Hence, if the thickness of PI film after curing is 2 \( \mu m \), the spun PI film thickness should be 2.5 \( \mu m \) (according to Table 1), and the spinning speed should be about 2800 r/min.

It can be seen from Table 2 that when the curing temperature is lower than 170 °C, the PI film can be etched by the developer easily. On the other hand, when the curing temperature is higher than 200 °C, the PI film almost cannot be etched by the developer. If the curing temperature of PI is lower than 170 °C, the contact hole in PI can be etched by developer during photolithography, and thus making the process simpler. However, if the soft curing temperature is higher than 170 °C, the contact hole cannot be etched completely before photoresist floating (see Fig. 3).

The deposition temperature of a-Si films in the self-supporting structure is 250 °C. Thus, the etching rate should be lower than 200 nm/s, so the PI cannot be removed by wet etching of the developer.

It can be seen from Table 3 that the etching rate decreases with increasing the curing temperature. The plasma etching rate is always higher than 200 nm/s. Thus, this plasma etching condition is suitable for sacrificial layer releasing.

The 160×120 self-supporting micro-bridge structure arrays are successfully fabricated by this process. The products are visualized by SEM (JSM-840 and JSM-6460, JEOL, Japan) as shown in Figs. 4 and 5.

In conclusion, the self-supporting micro-bridge structure based on a-Si films for applications as a bolometer is designed and fabricated. A series of key parameters are obtained. The spinning speed is about 2800 r/min. The wet etching time of PI is 65 s. The curing temperatures of soft and hard cured PI are lower than 170 and 250 °C, respectively. The plasma etching parameters are set as 2-Pa pressure, 120 sccm \( O_2 \) flow, and 150-W RF power. With these parameters, 160×120 self-supporting micro-bridge structure arrays are successfully fabricated.

References