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

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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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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 micromachining 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 corporation of America (RCA) cleaning using the spin coater (kW-4A, Institute of Micro electronics of CAS). It was done in two steps. Firstly, the rotating speed was set at 500−1000 r/min for 18 s. Secondly, the rotating speed was set at 3000−4500 r/min for 60 s. The thickness of PI was tested by the film thickness tester (MP-100 s, Mission peak Optics Inc., USA). The curing temperature can change the thickness of PI. In this experiment, an rapid thermal process (RTP-500 Beijing East Star Application of Physics Institute) equipment was used for curing at the temperature of 190−220 °C. In the manufacturing procedure of the self-supporting micro-bridge structure, the PI film needs to be patterned[6], and the contact holes in the PI film should be etched. If the curing temperature is lower than a certain value, the contact hole in the PI can be etched by the developer for positive photoresists, so this value is a key parameter. After the a-Si film was deposited using plasma enhanced chemical vapor deposition (PECVD), it was patterned using inductively coupled plasma (ICP-98A, Institute of Microelectronics of CAS). Then, 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 O_2 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

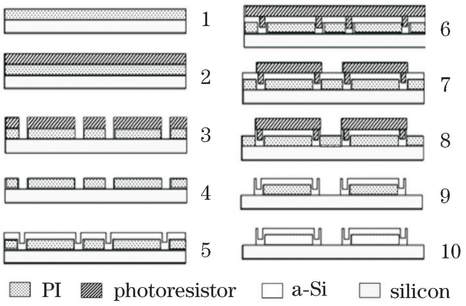

Fig. 1. Procedures of self-supporting micro-bridge based on a-Si film.

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 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 prebaked 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.

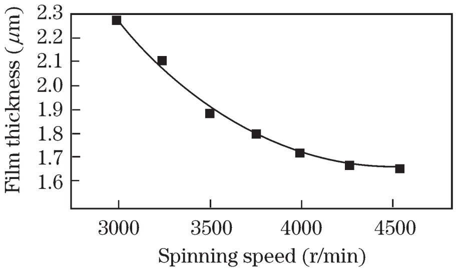

Fig. 2. Relationship between the film thickness and the spinning speed.

Table 1. Influence of Curing Temperature on PI Thickness

Temperature of Curing (°C)	Thickness before Curing (nm)	Thickness after Curing (nm)	Ratio of Thicknesses after and before Curing (%)
190	26472	22155	83.7%
190	28672	23708	82.7%
200	27665	22303	81%
200	27310	22020	81%
210	28695	22895	80%
210	27654	22145	80%
220	27905	21807	78%
220	27621	21736	78.6%

Table 2. Relationship Between Wet Etching Rate and Curing Temperature

Temperature (°C)	Thickness before Etching (Å)	Thickness after Etching (Å)	Etching Time (s)	Etching Rate (Å/s)
140	24680	16513	3	2722
150	25339	19482	2.5	2343
160	24869	19040	4	1457
170	17736	8862	15	444
180	23627	18103	40	138
190	22155	16991	50	103
200	22303	16406	60	98
210	22895	22321	60	10
220	21807	21534	90	3

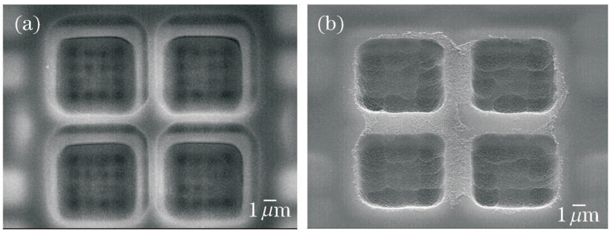

Fig. 3. SEM photos of the contact hole which is not etched completely with different soft curing temperatures. (a) 170 °C; and (b) 190 °C.

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

Table 3. Relationship Between Plasma Etching Rate and Curing Temperature

Temperature (°C)	Thickness before Etching (nm)	Thickness after Etching (nm)	Etching Time (s)	Etching Rate (nm/s)
140	2496.3	1737.8	3	252.8
150	2469.7	1774.1	3	231.9
160	2552.7	1860.9	3	230.6
170	2521.5	1871.1	3	216.8
180	2495.0	1788.1	3	235.6
190	2370.8	1735.8	3	211.7
200	2202.0	1548.8	3	217.7
210	2214.5	1564.8	3	216.6
220	2273.6	1670.1	3	201.2

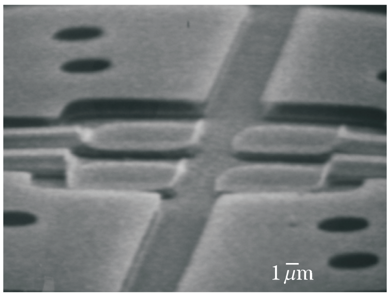

Fig. 4. SEM photo of self-supporting micro-bridge structure.

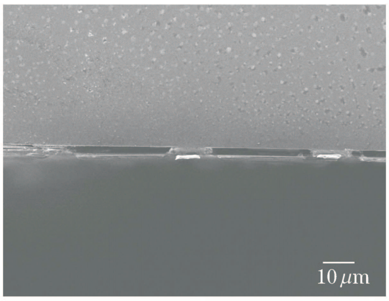

Fig. 5. Cross-section SEM photo of self-supporting micro-bridge structure.

$$d = \lambda_0/4n,$$

where n is the refractive index and $n = 1$ in vacuum, λ_0 is the infrared center wavelength and $\lambda_0 = 8$ μm in this uncooled infrared detector. As such, the thickness of PI is 2 μm, 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 μm, the spun PI film thickness should be 2.5 μm (according to Fig. 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 0.3 nm/s, so the PI cannot be removed by wet eteching 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.

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