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Impact resistance and static strength analysis of an extremely simplified micro hotplate with novel suspended film

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ABSTRACT

To improve mechanical strength of suspended micro hotplate, we proposed several innovative shapes of suspended films which were generated by different etching windows in this paper. Impact resistance and static strength are two important aspects of mechanical property. Half-sine acceleration load simulation was used to investigate impact resistance, and static load simulation was used to investigate static strength, proving better mechanical strength of design 5 and 6. Then, these micro hotplates were fabricated with less layers of $Pt/Si_3N_4/SiO_2$ or Pt/SiO_2 on Si substrate by the most simplified MEMS process flow. Drop tests proved that specimens could maintain intact even under the vibration load of 1000G. Micro force displacement test illustrated ultimate point loads that could be tolerated by these designs, thus revealing that the shape and material of suspended membrane would affect strength of the micro hotplate. The experimental results agree with simulation results, and prove that two new designs (design 5 and 6) have better mechanical strength than traditional suspended four-beam structure.

1. Introduction

Micro hotplates based on MEMS technology have important applications and great potential in the fields of gas sensors, infrared emitters, gas flow meters, micro calorimeters and infrared light sources [1–3]. Among these, the most extensive application is gas sensor. The gas sensing performance of most metal oxide gas sensors depends on the operating temperature, so the use of micro hotplates can integrate the heating element and the sensing element together and optimize the performance of the gas sensors [4].

Until now, most of the researches on MEMS devices have focused on developing advanced fabrication techniques and improving functional performance. For gas sensors, usually the most concerned performance indicators are size, energy consumption, response speed, maximum operating temperature, etc [5]. Relatively, mechanical characterization, reliability and long-term life have been rarely studied [6]. S.Z. Ali [7] studied on the deformation caused by residual stress, and the sources of residual stress contained the internal stress caused by the growth mechanism and the thermal stress due to the mismatch between layers of different materials. A few previous studies considered thermal stresses generated by electrifying to the micro hotplate [8], but the deformation and structural strength under different external loads have not been studied. However, when applied to gas sensors or other MEMS devices, the micro hotplate may be subjected to various forms and magnitude of external forces during production, transportation and usage. Especially for gas sensors with sensitive substance dropping on the micro hotplate, the mechanical strength of the micro hotplate is critical. It is necessary to study the mechanical properties of the structure, by comparing the mechanical properties of different designs, a more reliable design can be selected.

Some literatures reported the change of the number and location of beams. F.T. Zhang [9] presented a Pirani vacuum gauge based on a micro hotplate supported by six unequal beams, while F. Solzbacher [10] gave a kind of micro hotplate with six symmetrical beams. Literature [11] showed micro hotplates with different layouts in the location of arms. On the other hand, some studies focusd on the use of different substrates for micro hotplate and gas sensors based on micro hotplate [12]. The most widely applied was silicon substrate [13] and SOI [7,14], because a series of conventional MEMS processing technology can be used with Si material and it has good compatibility with CMOS. Alumina ceramics was used to fabricate micro hotplate in [15,16], for the advantage of alumina is perfect adhesion of platinum compared to silicon oxide or silicon nitride material even after annealing at high temperature. There are also

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other substrates such as glass [17], polyimide [18], etc. However, many of these designs use stacked structures and the process is often complicated.

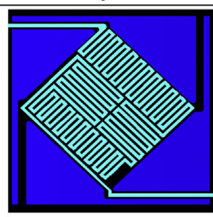
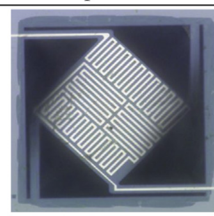
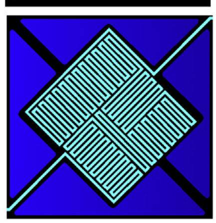
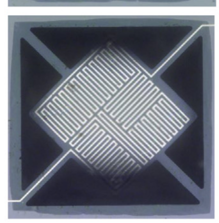
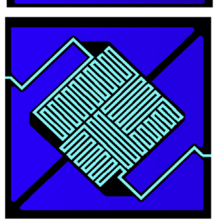
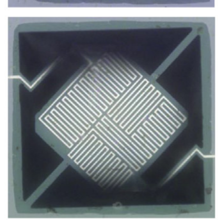
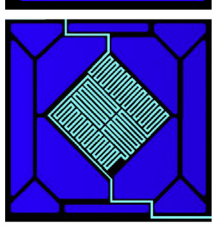
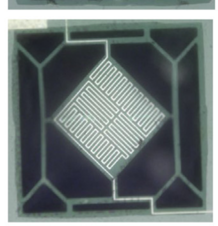
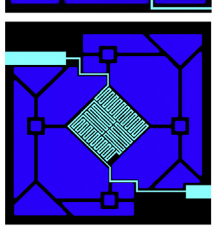
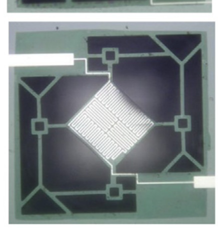
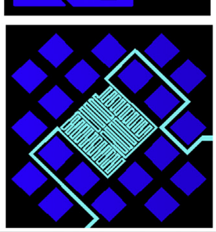
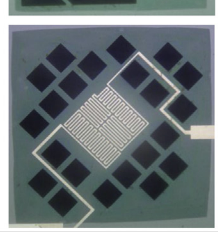
There are two types of micro hotplate structure: the closed-membrane type, and the suspended-membrane type [19]. Suspended-membrane type micro hotplates are always considered to meet the challenge of mechanical stability [20]. In this paper, we designed and fabricated the suspended-membrane coplanar micro hotplate of different shapes with Pt heater, unique shapes of Si_3N_4/SiO_2 insulating layer and Si substrate. The impact resistance and static performance of the micro hotplate were tested and compared with simulation results to prove novel designs a pretty good mechanical property.

2. Design and fabrication

2.1. Structure design of different suspended shapes

Mechanical properties of micro hotplates are related to the shape and the material of the suspended film. In this paper, we changed the designs of the etching window to avoid the accumulated mechanical stress, thus obtained higher strength. All the designed layouts and images of specimens taken by VHX-5000 super-deep three-dimensional microscopic system (Keyence, Japan) have been shown in Table 1. The design 1 imitated the Figaro shape which presented four arms [20]. On this basis, design 2 and 3 changed the position and distribution of the arms. However, as shown in micrograph, the corners of platform bended because of

Table 1
Several new designs of micro hotplate.

Number	Layout	Specimen	Max deflection (μm)
1			16.26
2			14.84
3			16.45
4			10.09
5			5.55
6			3.03