# Hybrid Device for Noise Reduction with Micro-Nano Material and Silicon Micro-Perforated Panel Resonator

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**Abstract:** A novel method was adopted for noise reduction, which added micro-nano ZnO structure into the micro-perforated panel (MPP) resonator. MEMS technology was employed to fabricate the well aligned micro perforators on the silicon panel, and the radius of the perforator was about 100 μm. The silicon panel and a rigid bracket constituted the MPP resonator. The micro-nano ZnO material synthesized by hydrothermal method was deposited onto the back panel in order to form a kind of hybrid device for noise reduction. Acoustic absorption experiments were carried out, and the results proved that the accuracy fabrication by MEMS technology was able to form MPP resonator with good noise absorption, and appropriate micro-nano ZnO structures on back panel enhanced the noise absorption of the device. The average absorption coefficient of the hybrid device increased by 2.54%, and reached 85.87% in the frequency band from 1 500 Hz to 6 000 Hz. The improvement was obvious especially in the frequency band from 1 500 Hz to 3 000 Hz. It can be concluded that the hybrid device with micro-nano ZnO structure and silicon MPP resonator had a better noise absorption capability.

**Keywords:** micro-nano ZnO structure; micro-perforated panel resonator; MEMS; hybrid device for noise reduction

# 微纳材料修饰的硅基微穿孔板共振降噪复合器件

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**摘 要:** 探索了一种通过 MEMS 技术制备硅基微穿孔板共振降噪结构，并进一步将 ZnO 微米纳米材料加入其中以提高吸声性能的新方法. 采用 MEMS 技术在硅片上得到了孔径为 100 μm、一致性良好的微孔阵列，将其与刚性底座组合在一起，构成硅基微穿孔板降噪器件. 将通过水热合成法得到的 ZnO 微米纳米材料制备在后底板硅片上，并与硅基微穿孔板组装在一起，构成微米纳米复合降噪器件. 对上述两种器件进行降噪实验，结果显示采用 MEMS 精密加工技术能够获得吸声系数较高的共振降噪器件，而经过 ZnO 微米纳米材料修饰后的复合器件，其在 1 500 ~ 6 000

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Hz 频段内的平均吸声系数提高了 2.54%,达到 85.87%. 这一现象在 1 500 ~ 3 000 Hz 频段尤为明显. 因而,采用 ZnO 微米纳米材料修饰后的复合器件,吸声性能有所提升.

**关键词:** ZnO 微纳米结构; 微穿孔板共振器; MEMS; 降噪复合器件

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The micro-perforated panel (MPP) resonator is used widely for its good capability of noise reduction. There have been many related developments in this field. Tayong in Université de Bourgogne found that the maximum of MPP absorption is the function of the flow velocity at high level of excitation[1]. Sakagami *et al* revised the theory of double-leaf MPP[2], studied the numerical method of double-leaf MPP[3], and did research on the relationship between the sound absorption of MPP and panel/membrane type absorbers[4]. Liu *et al*[5] enhanced the attenuation of the MPP by partitioning the back cavity. While most of the resonators mentioned above were manufactured by machining, the resonator with dense and tiny (the diameter is less than 0.2 mm) holes on the MPP would be difficult to produce. However, reducing the diameter is able to enhance the resistance of the micro holes and widen the absorption band according to the theory of MPP. Thus, MEMS technology is applied to fabricating the resonator with better capability in this paper.

Micro-nano ZnO materials have also been adopted in the MPP resonator mentioned above for further increase of absorption coefficient. It was reported that the ZnO materials have functions of increasing the acoustic absorption of porous materials[6]. Guo[7] studied the sound absorption properties of polyurethane/ZnO nanoparticle composites, and found that the composites show the best capability of noise absorption (the absorption coefficient is higher than 90% in 6 000—21 000 Hz band) when the content of ZnO nanoparticle is 5% (mass fraction), but the effect decreases drastically when the noise frequency is below 6 000 Hz. MPP resonator is suitable for low frequency noise absorption, and research about the influence of micro-nano ZnO materials on MPP resonator is still deficient. Thus a kind of novel hybrid device with micro-nano ZnO materials and the MPP resonant structure is made to explore a new way of solving the problem mentioned above. The acoustic absorption experiments were also carried out to test the performance of the hybrid device.

## 1 Theory of MPP resonator

The structure sketch of MPP can be seen in Fig. 1 and Fig. 2. Assume that the diameter of the micro perforator, thickness of the panel and the distance between two perforators are expressed as $d$, $t$ and $b$, respectively. The air density is $\rho = 1.2\ \mathrm{kg/m^3}$, the sound speed in air is $c = 340\ \mathrm{m/s}$, and the dynamic viscosity of air is denoted by $\eta = 1.789\ \mathrm{kg/ms}$. Here $f$ represents the resonant frequency, $\rho_p$ is the density of the perforators, and $D$ is the depth of the back cavity. The relative acoustic impedance $Z_r$ of MPP in the air could be expressed as Eq. (1). The optimum parameters can be calculated by Eq. (1) with traversal algorithm, as shown in Tab. 1, where $B$ is the half absorption bandwidth[8] and it is defined as Eq. (2).

$$Z_r = r + \mathrm{j}\omega m \tag{1}$$

where $r$ is the resistance, $r = \frac{0.147}{d^2}\frac{t}{\rho_p}K_r$, $K_r = \sqrt{1 + x^2/32} + 0.1768xd/t$, $x = 10d\sqrt{f}$; $\omega m$ is the reactance, $\omega m = 1.847\frac{ft}{\rho_p}K_m$, $K_m = 1 + \sqrt{\left(9 + \frac{x^2}{2}\right)} + 0.85 \cdot \frac{d}{t}$.

$$B = \frac{\Delta f}{f} = \frac{(1 + r)\omega D}{c} \tag{2}$$

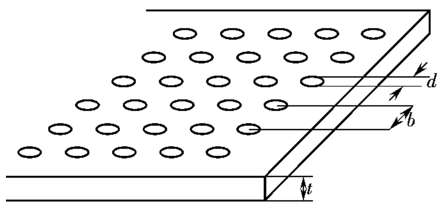



**Fig. 1 Structure sketch of MPP**

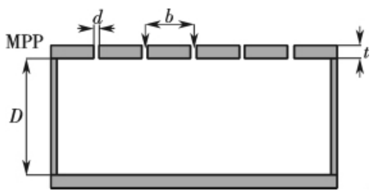



**Fig. 2 Structure sketch of MPP resonator**

**Tab. 1 Optimum parameters of MPP resonator**

| Parameters | Value |
|---|---|
| $d/\mu m$ | 100 |
| $t/\mu m$ | 290 |
| $b/\mu m$ | 400 |
| $f/Hz$ | 3 000 |
| $D/mm$ | 19.62 |
| $B$ | 2.21 |
| Maximum absorption coefficient | 0.99 |

## 2 Fabrication of MPP resonator and hybrid device

The silicon wafer was boiled in oil of vitriol and deionized water insequence, then $Si_3N_4$ layer was grown on both surfaces of the wafer by means of LPCVD. One side of the $Si_3N_4$ layer was removed in the ionized $SF_6$ gas, and wet etching process was used to reduce the thickness of the silicon panel to a proper degree. Aluminum layer was evaporated onto the other side to be a cover layer in the DRIE process. AZ1500 photoresist was used in lithography process to form the graph of micro perforators, and then the wafer was put into pure $H_3PO_4$ solution to eliminate the aluminum layer, which was in the micro perforators. Then the ionized $SF_6$ gas eliminated the exposed $Si_3N_4$ layer so that the silicon can be etched by the DRIE process. The finished MPP was put into acetone and pure $H_3PO_4$ solution in sequence to eliminate photoresist and residual aluminum layers, separately. The fabrication schematics are shown in Fig. 3, and the photograph of MPP can be observed in Fig. 4.

Micro-nano ZnO structure was grown in aqueous solution of zinc nitrate hydrate and methenamine at 95 ℃[9-14]. The silicon panel was immersed into the aqueous solution, then the vessel was placed in the furnace and the temperature was kept constant at 95 ℃. Micro-nano ZnO structure would be produced in solution and deposited onto the surface of the silicon panel. Six hours after the reaction started, the panel was fetched out of the aqueous solution. It was dried in furnace at high temperature. The photograph of the silicon panel with micro-nano structure can be seen in Fig. 5, and white material can be observed on its surface. Fig. 6 shows the SEM images of the micro-nano ZnO structure. ZnO flower can be found in the graph, and it was formed by nanorods with different dimensions. The diameter of the larger nanorod was about 500 nm, while that of the smaller nanorod was just about 200 nm. These ZnO flowers heaped up and formed a layer of porous material.

The MPP and the rigid bracket without micro-nano ZnO structure on bottom panel can form an MPP resonator. The resonator was fabricated by MEMS technology. The dense micro perforators were batch fabricated at one time, and the diameter of the perforators decreased to 100 μm. The MPP and the rigid bracket with micro-nano ZnO structure on the bottom panel constituted the hybrid device for noise reduction. Its photograph is shown in Fig. 7.

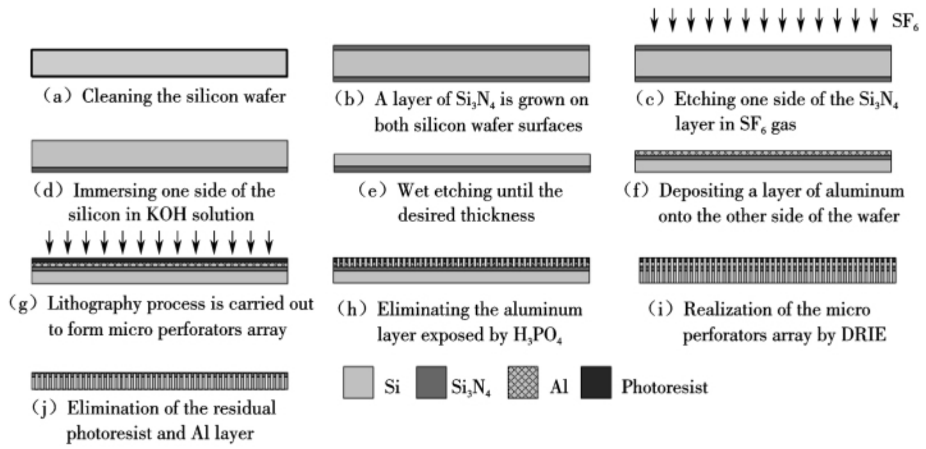
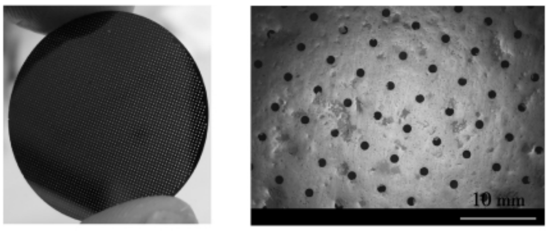



**Fig. 3 Fabrication schematics of MPP**



(a) Photograph　　(b) SEM image

**Fig. 4　Photograph and SEM image of MPP**

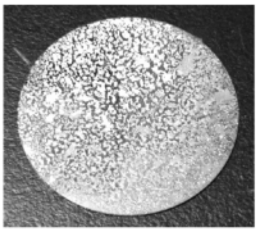
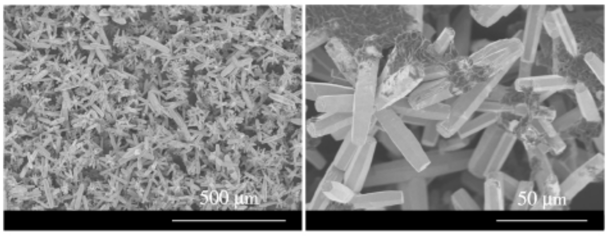


**Fig. 5　Photograph of silicon panel with micro-nano ZnO structure**



(a) In low magnification　　(b) In high magnification

**Fig. 6　SEM images of micro-nano ZnO structure**

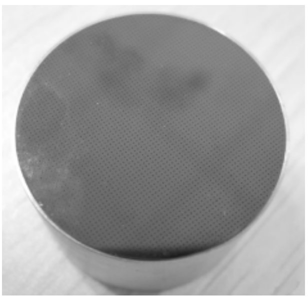


**Fig. 7　Photograph of hybrid device**

## 3　Experiment results and analysis

The noise absorption experiment was carried out to investigate the capability of noise reduction of two different devices. The experiment results can be observed in Fig. 8. In the graph, the circle points are the experiment data of the MPP resonator which was fabricated by MEMS technology. The dash line is the least squares curve of the MPP resonator. The star points are the experiment data of the hybrid device, and the solid line is its least squares curve.

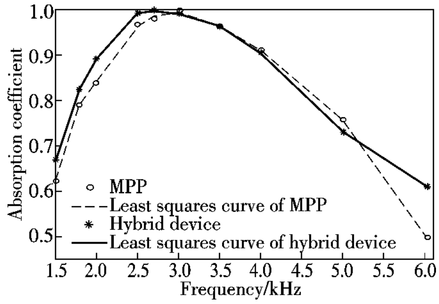



**Fig. 8　Absorption coefficient of MPP and hybrid device**

The results show that the MPP resonator has good acoustic absorption in frequency band from 1 500 Hz to 6 000 Hz, the average absorption coefficient in experiment band reaches 83. 33%, the maximum absorption frequency is at about 3 000 Hz, and the maximum absorption coefficient is 99. 8%.

The noise absorption characteristics of the hybrid device were also investigated. Experiment results reveal that the hybrid device had a very good acoustic absorption in frequency band from 2 500 Hz to 3 000 Hz. The average absorption coefficient reached 85. 87%, which was higher than that of the MPP resonator. In detail, it can be observed that the hybrid device had better absorption capability than the MPP resonator in lower frequency band from 1 500 Hz to 3 000 Hz. This means that certain micro-nano ZnO structure may be helpful to acoustic absorption in lower frequencies.

## 4　Conclusion

Hybrid noise reduction device with micro-nano ZnO structure and MPP resonator was successfully fabricated by MEMS and nano technologies. The capabilities of both the MPP resonator and the hybrid device were investigated in this paper. Experiment results show that the MEMS fabrication was able to form good noise absorber in commonly used frequency band from 1 500 Hz to 6 000 Hz, and appropriate micro-nano ZnO structure on back panel was helpful to enhancing the noise reduction characteristics of the device. The average absorption coefficient of the hybrid device in experiment band reached 85.87%, showing excellent ability of acoustic noise reduction in lower frequencies.

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