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用 UV-LIGA 技术制造大通孔率精细镍网

明平美[1,2],朱 荻[1],周 锋[1],胡洋洋[1],曾永彬[1]
(1. 南京航空航天大学 江苏省精密与微细制造技术重点实验室,江苏 南京 210016;
2. 河南理工大学 机械与动力工程学院,河南 焦作 454000)

摘要:高开孔率、大厚度金属精细网板的制造是网板业界的技术难题。分析了现有的精细金属网板制造工艺的优缺点,并提出采用基于 SU-8 光刻胶的 UV-LIGA 技术来制备高开孔率大厚度精细金属网板的工艺思路。优选了关键工艺环节的操作参数,表征了试样的形貌特点,检测并分析了试样的相关性能。结果显示,采用优化的工艺条件(前烘 65 ℃/20 min,95 ℃/20 min;适量曝光剂量;后烘 65 ℃/10 min,95 ℃/15 min;匀胶后静置、随炉冷却;超声辅助显影等)所制备的六边形镍网(边 200 μm),不仅开孔率高(88%),厚度大((120±3) μm),且具有尺寸精度高(形位误差±2 μm)、孔形一致性好(筋宽偏差<3 μm)、孔壁平滑等特点。结果表明,UV-LIGA 技术是一种制备高通孔率、大厚度精细金属网的有效工艺手段。

关 键 词:精细网片;高开孔率;UV-LIGA;高深宽比
中图分类号:TN405;TN305 **文献标识码:**A

Fabrication of metal micro-precision sieves with high open areas using UV-LIGA process

MING Ping-mei[1,2],ZHU Di[1],ZHOU Feng[1],HU Yang-yang[1],ZENG Yong-bin[1]

(1. *Jiangsu Key Laboratory of Precision and Micro-manufacturing Technology*, *Nanjing University of Aeronautics & Astronautics*, *Nanjing* 210016,*China*;
2. *School of Mechanical and Power Engineering*, *Henan Polytechnic University*, *Jiaozuo* 454000,*China*)

Abstract: The manufacture of thick micro-precision sieve-sheets with high open areas is a key technical challenge. After analysis on the process limitations existing in three manufacturing methods for metal micro-precision sieves, an optimized UV-LIGA technique based on SU-8 photoresist is presented to manufacture the micromesh nickel sieve-sheets. Operational parameters of some key process steps for fabricating micro-precision sieve-sheets are determined experimentally, and morphological characteristics of electroformed hexagon micromesh nickel sieves are evaluated using a SEM and an optical profiler. Experimental results show that, using the UV-LIGA process, hexagon micromesh nickel sieves (200 μm in side length,50 mm in diameter and 120 μm in thickness) with an open-area percent of 88% and a sheet-thickness of 120 μm, which can hardly be achieved by the conventional machining meth-

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ods, are successfully machined. The machined sieves are characterized by their smooth surfaces and aperture walls, high precision sizes as well as rigid and homogeneous structures. These results show that the UV-LIGA is an excellent method for fabricating micro-precision metal sieves.

Key words: micromesh sieve; high open area; UV-LIGA; high aspect ratio

1 Introduction

Precision metal sieve-sheets coming in many alloys have been used in a wide range of applications, such as centrifuge screens, sugar screens, filter screens, coffee filters, filter media for filter elements, filter candles, metal filters, pressure leaf filters, spinpack filters, test sieves and many others[1]. Some of the popular alloys are stainless steel, nickel, brass, copper, gold, etc. Precision metal micromesh sieve-sheets are usually produced by one of the three manufacturing techniques: etching, laser cutting and electroforming[2-3]. Although with the most cost-effective and the quickest turnaround, chemical-etching process has a limitation in the aspect ratio (thickness: aperture opening <1 : 1.5), and is difficult to produce a quality sieve-sheet with pitches smaller than 0.5 mm due to an undercut effect. Laser-cutting is generally a fabrication method with excellent positional accuracy and reproducibility, but a "scallop-like" outline in the resultant apertures having roughed walls, together with its "one-aperture-a-time" manufacture mode, greatly limits its application for fabricating precision micromesh metal sieve-sheets with ultrafine pitches. Electroforming, an additive rather than a subtractive process like etching and laser-cutting, has several advantages over punching, etching, laser-cutting and EDM process in fabricating precision metal sieve-sheets. These advantages include extreme high precision, no burrs, no stress, smooth metal surface and aperture walls, rigid and homogeneous structures, naturally flat products, design flexibility, sharp edge definition, excellent reproducibility, economical tooling and parts. It is a highly cost-effective method for prototyping or producing small and large series of metal sieve-sheets with ultra-fine pitches (0.02 mm to 0.04 mm). However, it is very difficult to be used to create the micro-precision sieves with an open percent exceeding 85% and simultaneously a sheet-thickness exceeding 0.1 mm.

The open area percentage is an important econotechnical norm for some applications of metal sieve-sheets. For example, under the given aperture-shape and hole size conditions, the bigger the open area percentage is, the higher the efficiency of filtration or separation is. Today, to increase the open-area-percentage of micromesh sieve-sheets, we have to increase the hole-size at a cost of lowering filtration or separation grade or narrowing ribs of sieves with a simultaneous reduction in thickness. This is because there are various process limitations in the existing three manufacturing methods. It will be very desirable to increase open-area-percentage of micromesh sieves without changing the hole-size or reducing the thickness of the sheets. But it may be involved in the manufacturing problems of high-aspect-ratio microstructures. In this case, a bigger open-area-percentage means a less rib-width (or pitch), and hence an increase in the aspect ratio. It is necessary to exploit or search for some new techniques to meet these fabrication requirements.

UV (Ultra Violet)-LIGA (a German acronym standing for the main steps of the process, i. e. lithography, electroforming, and plastic moulding) using SU-8 resist, is an excellent High Aspect Ratio Microsystems (HARMS) process which allows to overlap a majority of the field of X-ray LIGA applications while enabling low costs and short throughput time[4]. It integrates thick-resist lithography and electroforming steps. Microcomponents from Ni, Cu, Au, and Ag with a structure-feature height up to 500 μm, minimal lateral dimension down to 8 μm, sharp and smooth sidewalls, and an aspect ratio up to 10 have been achieved[5-7]. These typical process advantages may endow the UV-LIGA technology with the feasibility of manufacturing metal micro-precision sieves with high open areas in a relatively-higher thickness.

In this work, a nickel hexagonal micromesh sieve with an open area percentage above 85% and a sheet-thickness above 0.1 mm is fabricated tentatively by the UV-LIGA process based on SU-8 resist. The SU-8 resist is used as a UV resist because of its very high optical transparency above 360 nm, which makes it ideally suited for imaging fine structures with near vertical sidewalls in very thick films. After SU-8 resist moulds fabricated employing UV lithography, they are filled with nickel by the microelectroforming process, and precise nickel micromesh sieves are subsequently obtained. To analyze the feasibility of fabricating thick micromesh sieve-sheets with the open area percentage using the UV-LIGA technology, some performances such as open area percentage, hole size distribution, and tolerance are evaluated.

2 Design

In order to obtain a larger open area percentage, a hexagonal opening is selected, as shown in Fig. 1. In terms of hexagonal openings in sieves, the open area percentage (K) can be computed by the following formula[8]

$$K=(b/a)^2\times 100\% \ , \tag{1}$$

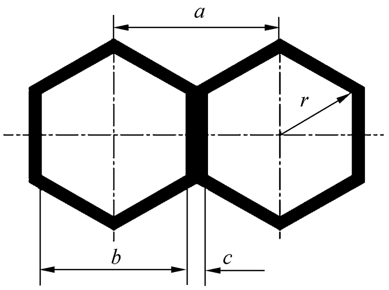


Fig. 1 Schematic diagram of hexagonal micromesh

Where a is the pitch of holes, b is the aperture of micromesh. a and b are given by

$$a=\sqrt{3}r+c, b=\sqrt{3}r \ , \tag{2}$$

Where c is the width of rib between the two adjacent openings, r is the radius of circumcircle of hexagonal micromesh. So the equation (1) can be expressed as

$$K=(\sqrt{3}r/\sqrt{3}r+c)^2\times 100\% \ . \tag{3}$$

It can be learned from the equation (3) that, the larger the radius r is and the smaller the rib width c is, the higher open area K is. In order to obtain a much higher open area percentage, the rib width c should be selected as small as possible. Given $r=200$ μm and $K=85\ \%$, rib width c should be 30 μm from the Eq. (3). In this case, the aspect ratio of ribs will be up to 4 if the thickness of 120 μm of the sheet is adopted.

3 Process details

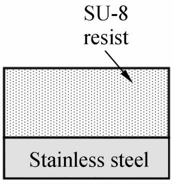
The main process steps are shown in Fig. 2. To be propitious to release the electroformed nickel sieve-sheets from the substrate, stainless steel substrate (50 mm in diameter, 0.4 mm in thickness) was designedly used. The details of the optimized UV-LIGA process for manufacturing the micro-precision sieves are as follows:

(1) After the substrate being carefully cleaned, a 120 μm-thick SU-8 2025 resist layer is spin-coated on the substrate with stepping spin speeds. And after the resist having been applied to the substrate, it is given a sufficient relax time to minimize the stress associated with the spin coat

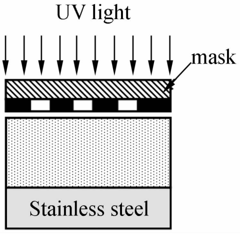
process. And then, a soft bake step is carried out on a hotplate, baking cycles of 65 ℃ for 20 min followed by 95 ℃ for 20 min. Subsequently, the photoresist is cooled down naturally to room temperature prior to its removal from the hotplate.

(2) As shown in Fig. 2 (b), exposed regions are obtained in the SU-8 photoresist by UV light irradiating with a contact mode. The UV-exposure dose is 260 mJ/cm^2.

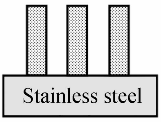
(3) Prior to development, the exposed SU-8 resist is baked first at 65 ℃ for 10 min followed by baking at 95 ℃ for 15 min on the hotplate. During the developing, patterned photoresist is rinsed in the MicroChem′s SU-8 developer with an ultrasonic stirring (frequency, 33 kHz ; power intensity, 2 W/cm^2) for 2—3 min, followed by rinsing with isopropyl alcohol for 10 s. And subsequently, it is dried on the hotplate at 95 ℃ for 1 min. The micro-moulds for nickel electroforming are shown in Fig. 3.



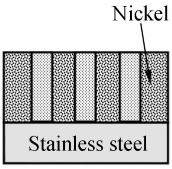
(a) Spin-coating



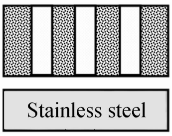
(b) UV-exposure



(c) Development



(d) Electroforming



(e) Removing resist

Fig. 2 UV-LIGA process schematic for fabricating microstructures in an SU-8 electroforming mode

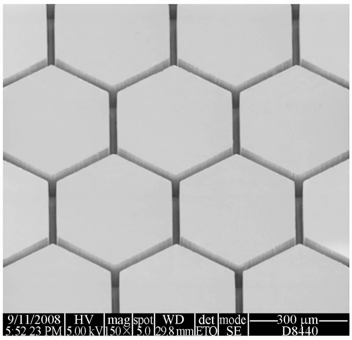


Fig. 3 SU-8 resist molds of micromesh sieve after development

(4) Microelectroforming in the patterned resists with high-aspect-ratio micro features has been still a tickler. Therefore, a novel electroforming process, named microelectroforming technique assisting low air-pressure alternately and temperature-gradient, which helps to significantly enhance mass transport, and to reduce the formation of gas bubbles as well as to quicken the eliminating of the dissolved gas during the microelectroforming[9], is applied to the electrodeposition of nickel in the patterned sieve-mould. Bath composition and deposition parameters are presented in Tab. 1. The cathode is positioned horizontally 20 mm or so far from the anode facing each other.

Tab. 1 Electrolyte composition and electrodeposition conditions

Bath Constituent	Amount or conditions
$Ni(NH_2SO_3)_2 \cdot 4H_2O$ (Concentrated solution)	420 ml/l
$NiCl_2 \cdot 6H_2O$	6 g/l
H_3BO_3	37.5 g/l
$NaC_{12}H_{25}SO_4$	0.1 g/l
Operating conditions Current density (DC)	300 A/m^2
Temperature gradient	Bulk electrolyte: 25 ℃, Cathode: 60 ℃
pH	3.3～3.8
Agitation	Forced flushing by airflow

(5) After electroforming, the un-exposed SU-8 structures are removed with NANO Removal PG (from MicroChem) by immersing mode at 80 ℃ with ultrasonic agitation (frequency, 33 kHz; power, 30 W). This is followed by a reactive ion etching process at 300 W RF power in 10% CF_4 and 90% O_2 ambient at 133.3 Pa and room temperature. Electroformed micromesh nickel sieve-sheet after removing resist is shown in Fig. 4.

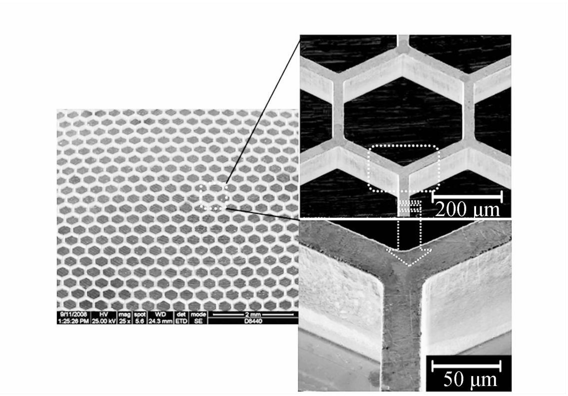
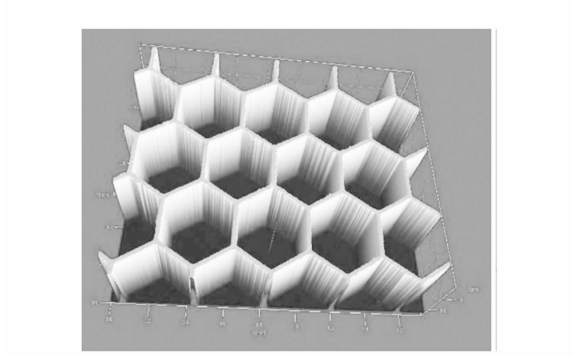


Fig. 4 Morphology of electroformed nickel micromesh sieve-sheet

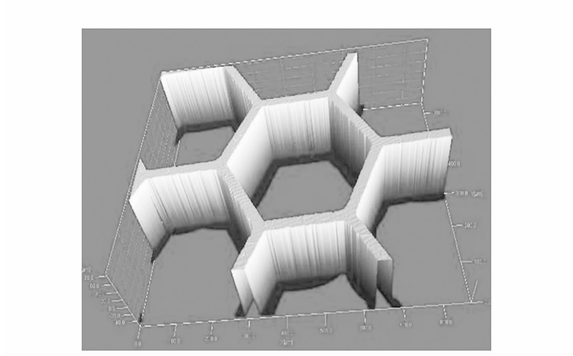
4 Results and analysis

Micromesh nickel sieve-sheet fabricated by the optimized UV-LIGA technique is characterized by excellent morphologies with very flat and smooth surfaces of aperture walls, sharp edge definition, rigid and homogeneous structures and almost no electrodeposition defects, as shown in Fig. 4.

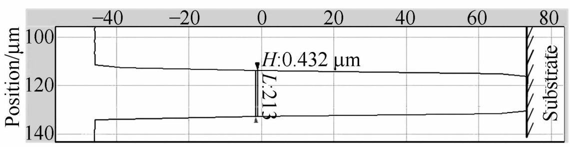
To evaluate structural characteristics as well as to analyze micromesh size variation of the electroformed sieve and compare with the designed openings, topography and rib-width of the electroformed sieve-sheet are also examined using an optical profiler typing MicroXAM (from ADE) and a tool measuring microscope typing MF-UA1740H (from Mitutoyo Ltd.), as shown in Fig. 5 and Fig. 6. Ribs characterized with a slight taper shape are presented (shown in Fig. 5(c)). The sizes of rib-width between the



(a) Topography of sieve



(b) Partial enlarged detail



(c) Rib profile

Fig. 5 Topography and rib profile of micromesh sieve

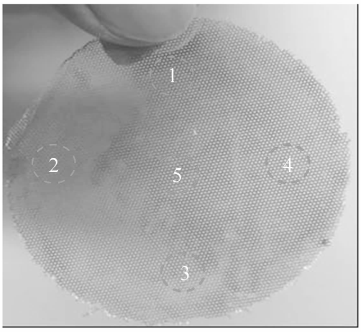


Fig. 6 Photo of nickel micromesh sieve-sheet

narrowest portion and the widest portion are in the range of 2 μm by measuring randomly five ribs. The reason for this is that the uppermost portions of the resist are more intensively exposed during the exposing, resulting in a tapering of the resist from an upper widest point to a narrowest point where the resist meets the carrier, and thus apertures having a trapezoidal cross section are produced. These built-in taper aperture walls together with smooth surfaces may help to make sieves easier to clean and reduce the possibility of clogging and particulate entrapment. The average rib-width of micromeshes measured at the half-height of rib in five different places (shown in Fig. 6 ① ～⑤ and Fig. 7) is 26. 16 μm, and there is a 3. 84 μm reduction comparing with the designed 30 μm width, which has practically increased the open area percentage of sieve-sheets up to 88%. A small air gap always forming between the mask and the negative SU-8 photo-resist which is not perfectly flat results in a light diffraction phenomenon which causes some absorption of ultraviolet radiation of un-patterned region (shown in Fig. 8), and therefore narrower trenches of resist moulds where nickel will be filled by electroforming process forms after developing.

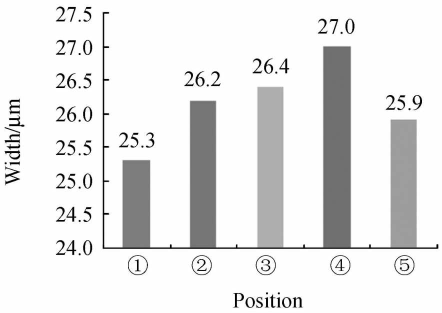


Fig. 7 Width of ribs of micromesh sieve-sheet measured in five different places

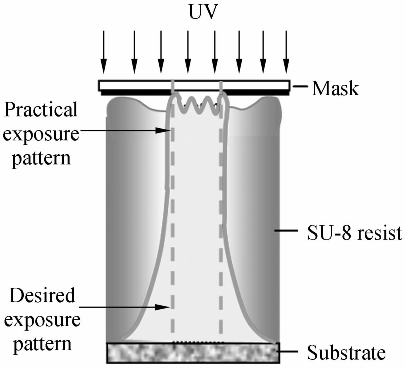


Fig. 8 Schematic diagram of SU-8 resist exposing with diffraction phenomenon

5 Conclusions

Hexagonal micromesh (200 μm in side-length) nickel sieve-sheets (50 mm in diameter, 120 μm in thickness) with open area percentage up to 88% are successfully obtained using an optimized UV-LIGA technique based on SU-8 photoresist and a novel electroforming process—microelectroforming assisting low air-pressure alternately and temperature-gradient. These sieve-sheets also feature smooth metal surfaces and aperture walls, no burrs, rigid and homogeneous structures, and sharp edge definition. Apertures with trapezoidal cross-section and plus or minus 2 μm tolerance are naturally achieved using this process, which may benefit filter media or printing stencil to be cleaned easily. It should be noted that, comparing to the designed value, the UV-LIGA-fabricated micromesh sieve-sheets, however, may have a little increase in the resulted open area percentage, which results from the inevitable light-diffraction effect during the resist's exposing.

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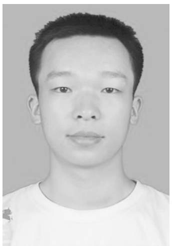
Authors' biographies:

MING Ping-mei (1974—), male, Ph. D., associate professor of Henan Polytechnic University, his researches focus on non-traditional machining and microfabrication. Now he is a poster-doctor at Nanjing University of Aeronautics & Astronautics. **E-mail**: mingpm@nuaa.edu.cn

ZHU Di (1954—), male, Ph. D., professor of Nanjing University of Aeronautics & Astronautics, his researches focus on non-traditional machining and microfabrication. **E-mail**: dzhu@nuaa.edu.cn



ZHOU Feng (1985—), male, M. S. student of Nanjing University of Aeronautics & Astronautics, his researches focus on non-traditional machining and microfabrication. **E-mail**: imagespace@163.com

HU Yang-yang (1984—), male, Ph. D. candidate at Nanjing University of Aeronautics & Astronautics, his researches focus on non-traditional machining and microfabrication. **E-mail**: hyy502@nuaa.edu.cn

ZENG Yong-bin (1977—), male, Ph. D., lecturer of Nanjing University of Aeronautics & Astronautics, his researches focus on non-traditional machining and microfabrication. **E-mail**: binyz@nuaa.edu.cn