Ultrasonics Sonochemistry 33 (2016) 10–17

Contents lists available at ScienceDirect

Ultrasonics Sonochemistry

journal homepage: www.elsevier.com/locate/ultson

# Enhancing the adhesion strength of micro electroforming layer by ultrasonic agitation method and the application

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ARTICLE INFO

*Article history:*
Received 18 March 2016
Received in revised form 15 April 2016
Accepted 15 April 2016
Available online 18 April 2016

*Keywords:*
MEMS
Micro electroforming
Ultrasonic power
Ultrasonic frequency
Adhesion strength
Polarization

ABSTRACT

Micro electroforming is widely used for fabricating micro metal devices in Micro Electro Mechanism System (MEMS). However, there is the problem of poor adhesion strength between micro electroforming layer and substrate. This dramatically influences the dimensional accuracy of the device. To solve this problem, ultrasonic agitation method is applied during the micro electroforming process. To explore the effect of the ultrasonic agitation on the adhesion strength, micro electroforming experiments were carried out under different ultrasonic power (0 W, 100 W, 150 W, 200 W, 250 W) and different ultrasonic frequencies (0 kHz, 40 kHz, 80 kHz, 120 kHz, 200 kHz). The effects of the ultrasonic power and the ultrasonic frequency on the micro electroforming process were investigated by polarization method and alternating current (a.c.) impedance method. The adhesion strength between the electroforming layer and the substrate was measured by scratch test. The compressive stress of the electroforming layer was measured by X-ray Diffraction (XRD) method. The crystallite size of the electroforming layer was measured by Transmission Electron Microscopy (TEM) method. The internal contact surface area of the electroforming layer was measured by cyclic voltammetry (CV) method. The experimental results indicate that the ultrasonic agitation can decrease the polarization overpotential and increase the charge transfer process. Generally, the internal contact surface area is increased and the compressive stress is reduced. And then the adhesion strength is enhanced. Due to the different depolarization effects of the ultrasonic power and the ultrasonic frequency, the effects on strengthening the adhesion strength are different. When the ultrasonic agitation is 200 W and 40 kHz, the effect on strengthening the adhesion strength is the best. In order to prove the effect which the ultrasonic agitation can improve the adhesion strength of the micro devices, micro pillar arrays were fabricated under ultrasonic agitation (200 W, 40 kHz). The experimental results show that the residual rate of the micro pillar arrays is increased about 17% by ultrasonic agitation method. This work contributes to fabricating the electroforming layer with large adhesion strength.


## 1. Introduction

As the developing of MEMS, micro metal devices including micro sensors, micro molds and micro actuators attract more and more attention. And the micro metal devices are suitable to be fabricated by the micro electroforming technology. Nevertheless, during micro electroforming process, the micro metal devices usually suffers from low adhesion strength. The low adhesion strength makes micro structures adhere weakly to the adjacent surface. This problem severely restricts the quality of the micro metal devices. Therefore, it is inevitable to research the method for improving the adhesion strength.

By exerting the ultrasonic agitation during electrodeposited process, performances of the electrodeposited layer (adhesion strength [1–4], fatigue strength [5], surface morphology [6], tensile stress [7–9], etc) can be improved. Nowadays, effect of the ultrasonic agitation on the adhesion strength is shown as following: by reducing the tensile stress at the transition area of the layer/substrate system, ultrasound-assisted electrodeposited method can fabricate multilayered Ni layer with large adhesion strength [1]. Moreover, in order to improve the adhesion strength, an interlayer between the electroplating layer and substrate can be obtained by the ultrasonic agitation method [2]. After the zincate pretreatment of substrate, the ultrasonic agitation improves the coverage of Zn layer on the substrate, which results in the

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http://dx.doi.org/10.1016/j.ultsonch.2016.04.021
1350-4177/

enhancement of the adhesion strength [3]. In addition, since the much larger internal contact surface area of the electroplating layer, the ultrasonic agitation can electroplate Platinum wire with large adhesion [4]. Therefore, according to these researches, the adhesion strength is increased by improving the characters of the electrodeposited layer such as the interlayer and the internal stresses. The interlayer can enhance the structural matching of electrodeposited layer on the substrate, which improves the adhesion strength. Besides, the internal stresses have bad effects on the adhesion strength, which encompasses the tensile stress and the compressive stress. The tensile stress generates film to crack and the compressive stress causes film to blister. Generally, the adhesion strength can be improved by reducing the internal stresses in the electrodeposited layer. And our previous work shows that the ultrasonic agitation method can improve the adhesion strength by reducing the compressive stress and increasing the internal contact surface area of the electroforming Ni layer [10]. However, in our previous work, the ultrasonic power is 250 W and the ultrasonic frequency is 40 kHz. This paper extends our previous work, and demonstrates the effect of the different ultrasonic power (0 W, 100 W, 150 W, 200 W, 250 W) and the different ultrasonic frequencies (0 Hz, 40 kHz, 80 kHz, 120 kHz, 200 kHz) on the adhesion strength. Besides, few researches have ever examined the effects of the ultrasonic agitation on the adhesion strength of the micro device. The purpose of this paper is also to investigate the effects of the ultrasonic agitation on the adhesion strength of the micro device.

In order to research the effect of the ultrasonic power and the ultrasonic frequency on the adhesion strength, the micro electroforming experiments were presented under ultrasonic agitation. The polarization and a.c. impedance methods were applied to research the effect of the ultrasonic power and the ultrasonic frequency on the micro electroforming process. The compressive stress was measured by the XRD method, the crystallite size was measured by the TEM method. The internal contact surface area of the electroforming layer was measured by CV method. The adhesion strength was measured by the scratch test. In order to prove the ultrasonic agitation method can improve the adhesion strength of the micro devices, micro pillar arrays were fabricated under the application of the ultrasonic agitation. The experimental results prove the effect of the ultrasonic agitation on the adhesion strength.

## 2. Experimental process

The experimental equipments and process can be seen in Ref. [10]. Comparing with the parameters of the ultrasound in Ref. [10], the ultrasonic power and the ultrasonic frequency were multiple during this experimental process. The experimental condition of the ultrasonic power is as following: the ultrasonic frequency is 40 kHz, and the ultrasonic power includes (0 W, 100 W, 150 W, 200 W and 250 W). The experimental condition of the ultrasonic frequency is as following: the ultrasonic power is 200 W, the ultrasonic frequency includes (0 kHz, 40 kHz, 80 kHz, 120 kHz and 200 kHz). After electroforming process, the crystallite size, the compressive stress and the adhesion strength were measured. The measure method can be seen in Ref. [10]. In order to measure the internal surface area of the electroforming layer which is contacting with the substrate, the electroforming layer was peeled off from the substrate after electroforming. Then the CV method was used to test the internal contact surface area of the electroforming layer which is contacting with the substrate [10]. TEM was used to evaluate the crystallite size [11,12]. Fig. 1 shows the crystallite images and electron diffraction images (insets) of the ultrasonic layer (40 kHz, 200 W) performed in TEM (JEM 2100F, Jeol Company, Japan).

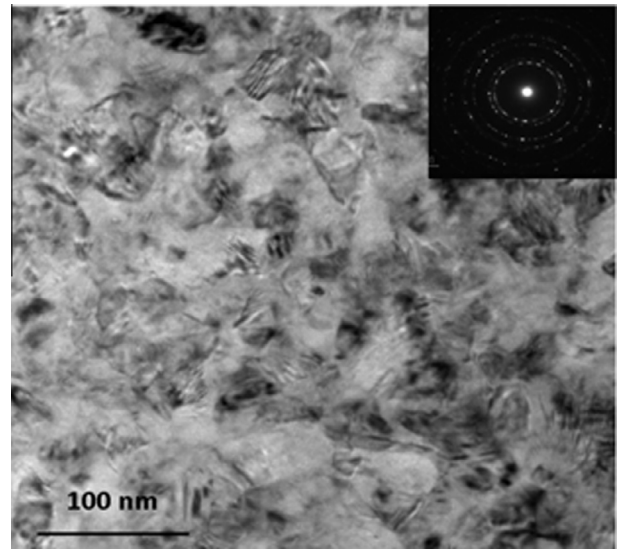


**Fig. 1.** TEM image of the ultrasonic layer (40 kHz, 200 W).

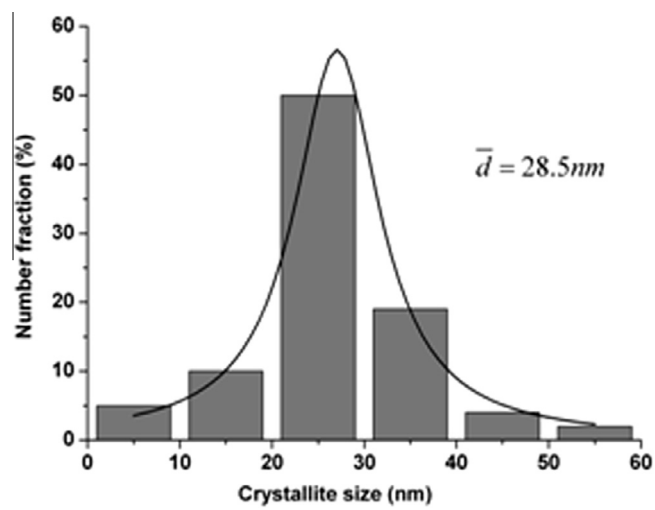


**Fig. 2.** TEM measured crystallite size distributions of the ultrasonic layer (40 kHz, 200 W).

Fig. 2 shows the crystallite size distributions of the ultrasonic layer (40 kHz, 200 W). The averaged crystallite size $\bar{d}$ was calculated from at least 100 randomly selected crystallite images.

The experimental results of the crystallite size and the compressive stress under the different ultrasonic power are listed in Table 1. The experimental results of the internal contact surface area and the adhesion energy under the different ultrasonic power are listed in Table 2. The experimental results of the crystallite size and the compressive stress under the different ultrasonic frequency are listed in Table 3. The experimental results of the internal contact surface area and the adhesion energy under the different ultrasonic frequency are listed in Table 4.

## 3. Results and discussion

### 3.1. The effects of the ultrasonic power on the adhesion strength

Fig. 3 shows the cathode polarization curves during the micro electroforming process with the different ultrasonic power.