Precision Engineering 47 (2017) 389–396

Contents lists available at ScienceDirect

Precision Engineering

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

Fabrication of various shaped tungsten micro pin arrays using micro carving technology

Jong Wuk Park[a], Haan Kim[a], Jang Gil Kim[b], Chong Nam Chu (Prof.)[a,*]

[a] Department of Mechanical Engineering, Seoul National University, 599 Gwanangno, Gwanak-gu, Seoul, 155-744, Republic of Korea
[b] BK21+ Transformative Training Program for Creative Mechanical and Aerospace Engineering, Seoul National University, 599 Gwanangno, Gwanak-gu, Seoul, 155-744, Republic of Korea

ARTICLE INFO

Article history:
Received 17 May 2016
Received in revised form 26 August 2016
Accepted 22 September 2016
Available online 24 September 2016

Keywords:
Micro pin arrays
Micro carving
Tungsten
Laser beam machining
Electrochemical etching
Shape control

ABSTRACT

This paper describes a state of the art in micro-structuring high strength metallic materials. Tungsten micro pin arrays in a variety of shapes are fabricated using a micro carving technology, which combines laser beam machining and electrochemical etching processes. First, micro pin arrays were rough-shaped by laser beam machining along a pre-defined scanning path to control their structural shape. The micro pin array in this stage had near-conical shape of structures due to a recast layer. Next, the genuine shape of micro pin arrays came to the surface via electrochemical etching process to elute the recast layer into electrolyte. Quantitative elemental analysis with energy-dispersive spectroscopy (EDS) was implemented to characterize the formation of recast layer on a micro pin structure after the laser beam machining process. The atomic percentage EDS maps indicated that higher percentage of tungsten was detected on the core micro pin structure, whereas relatively large percentage of oxygen was found on the recast layer (O 9%, W 91% in the center area, and O 53%, W 47% in the outer area).

1. Introduction

Near-pin shape of micro metal structures has been used in a wide range of applications, which require executing-specialized functions. A micro pyramidal structure can increase light extraction to improve the efficiency of LED flux utilization [1], and a metal micro pin is used during an electroencephalogram to measure brain and neural system signals [2]. A nano scale surface texturing study was carried out to assess anti-reflective functionality [3], and a micro pin-shaped structure was fabricated to separate oil from water [4]. In spite of their versatility, however, most of micro pin structures suffer from relatively low material stiffness and poor mechanical strength, which generally result from inherent material properties and structural weakness [5]. The use of high strength metallic materials such as tungsten, titanium and stainless steel can be considered as an alternative to improve those drawbacks. It will promise the high durability and reliability of micro pin structures so that they can withstand harsh environments.

Here a new challenge lies on finding a proper method to machine high strength metallic materials, because it is generally known to be difficult to cut. MEMS technology based on the semiconductor process, which has been widely used in fabricating micro structures, is not available any more owing to the limitation of materials [5,6]. Several non-traditional machining methods such as electrical discharge machining (EDM), electrochemical machining (ECM) and laser beam machining (LBM) might be applied to fabricate micro pin metal structures. Nevertheless, it remains a prerequisite to find a novel method for micro-structuring hard-to-cut metals with high throughput and low cost. Micro EDM process still has a tool wear issue resulting in long process time and high cost, even though it promises high quality products [7]. ECM would not be constrained by the tool wear problem, but similarly time-consuming process to fabricate micro pin structures on a large area. In spite of the merit of short machining time in LBM, low surface quality becomes problematic due to recast layer and burr after process [8].

In this paper, we propose a micro carving technology to precisely control the shape of a tungsten micro pin array. The problems due to the limitation of material were resolved by using high strength tungsten as workpiece material. Fig. 1 illustrates the schematic of micro carving technology, which consists of two successive steps as follows: (a) rough-shaping of a micro pin structure via laser beam machining with pre-defined scanning path, and (b) electrochemical etching to reveal the original micro pin structure. Laser beam machining enabled to fabricate various shapes of micro pin arrays with high throughput. Subsequently electrochemical etching was carried out for removing generated recast layer to achieve micro

* Corresponding author.
E-mail address: cnchu@snu.ac.kr (C.N. Chu).

http://dx.doi.org/10.1016/j.precisioneng.2016.09.012
0141-6359/

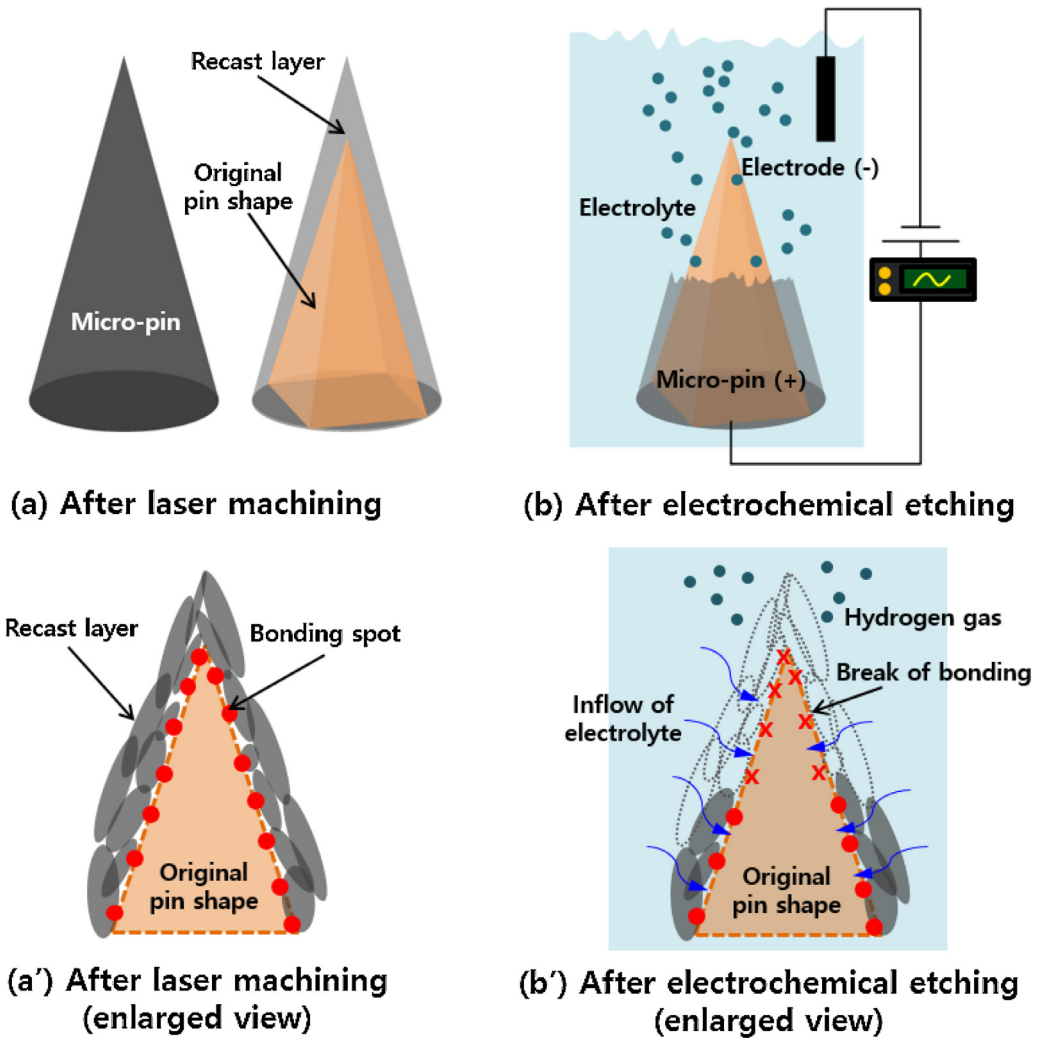

Fig. 1. Schematic of micro carving technology for fabricating a tungsten micro pin structure with a sharp cutting edge (a) micro pin structure after laser machining, (b) the final product after removing a recast layer by electrochemical etching, (a') and (b') enlarged view of each state.

structure with sharp cutting edges. This new method is thought to be a solution to improve surface quality problem that was caused by laser beam machining. In addition, shape control of tungsten micro pin structure was investigated depending on the scanning path of laser beam and electrochemical etching condition. The formation of recast layer during the process was characterized by EDS analysis.

2. Theoretical background

2.1. Rough texturing of micro pin array by laser beam machining with scanning path control

In this process, a micro pin array was fabricated on a 1 mm thick tungsten plate using laser beam machining. Fig. 2 illustrates the formation of micro pin array in a specific shape by controlling a scan path. When a focused laser beam is applied along the predefined path, the material on the scanned region (Zone A) would be removed by thermal ablation. The Gaussian-mode laser beam generally causes a tapered slope on the workpiece in ablation-dominated material removal process, and thus the remained part (Zone B) has sharp edge around the structure. In this principle of micro-structuring by LBM, micro pin arrays with sharp tips can be fabricated from a crisscrossed laser scanning path. It also allows to fabricate micro pin structures in a variety of shapes such as rectangle, triangle, and hexagon by changing laser beam scanning paths. Nevertheless, it had been expected from our previous study [9] that the micro pin array would have conical shape of structures due to a recast layer on the surface, which is inevitably produced during the LBM process. Hence a proper eliminating process to achieve the original shape of micro pin structures is required, and it will be detailed in the following section.

2.2. Removing recast layer by electrochemical etching

For the reasons mentioned above, the micro pin structures by LBM would have conical shape due to the recast layer, which should be removed for achieving sharp cutting edges. There have been several post treatment processes in LBM to remove the recast layer and burr of product, including as thermal process [10], under water process [11] and laser cleaning [12].

In this study, electrochemical etching was used to remove the recast layer and burr on the tungsten micro pin structures after LBM process. It facilitates an atomic level dissolution on a material surface, and thus it is widely used to post-process a workpiece for surface treatment [8]. Electrochemical etching also promises high throughput process as it can be simultaneously implemented on the entire substrate immersed into electrolyte. Moreover, it is beneficial for achieving sharp edge on the tip and symmetric cone shape