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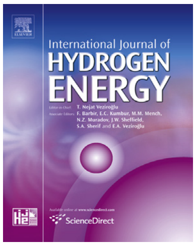

Laser micro-milling of microchannel on copper sheet as catalyst support used in microreactor for hydrogen production

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ABSTRACT

Microchannel structure as catalyst support has been widely used to construct numerous microreactors for hydrogen production. In this work, the laser micro-milling technique was introduced into the fabrication process of microchannels with different geometry and dimensions. The effects of varying scanning speed, laser output power and number of scans on the surface morphology and geometrical dimension of microchannels have been investigated based on SEM observations. It is found that the change of scanning speed and laser output power significantly affected the surface morphology of microchannel. Moreover, the depth of microchannel was increased when the laser output power and number of scans were increased. Subsequently, the microchannels on copper sheet fabricated by the laser micro-milling technique were used as catalyst support to conduct the methanol steam reforming reaction. The better reaction performance of methanol steam reforming in microchannels indicates that laser micro-milling process is probably suitable to fabricate the microchannel reactor for the commercial application.

1. Introduction

In recent years, microreactors have been widely used for conducting various catalytic and non-catalytic reactions with hydrocarbon fuels to generate the hydrogen source for mobile and miniaturized portable fuel-cell systems [1–3]. In general, the microreactors for hydrogen production can be classified into the packed-bed and microchannel reactors. Unfortunately, the existing packed-bed reactors with small dimension do not always provide an efficient design because of its large pressure drop and significant axial and radial temperature gradients in the packed bed [4–6]. Nowadays, the development of microchannel reactors for hydrogen production has gained an increasing interest due to the outstanding advantages of providing a portable and low cost hydrogen source for numerous applications such as fuel cells, vehicle and other power equipments [7–9]. In particular, the microchannel arrays as catalyst support in the microreactors exhibit many potential advantages because of their high surface-to-volume

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ratio. Moreover, the microchannels with small dimension give the short reaction time, introduce or remove the reaction heat, intensify mass and heat transfer as well as provide the larger interfacial area for reactants [10–13]. Therefore, the unique microchannel structures create an increase of new possible applications for different microreactors for hydrogen production.

Up to now, several technologies have been reported to fabricate the microchannel arrays with different geometry and dimensions, including chemical etching, lithography technique, electrical discharge machining (EDM), advance milling method, laser micromachining and other methods [14,15]. Chemical etching as one of nontraditional machining processes usually uses the etchant to remove the unwanted work piece material by controlled dissolution. Although this method has attracted a lot of attention due to its attendant advantages, such as low cost, fast processing, no burring on the edges of the walls and easy processing of very thin materials [16–18]. However, this method offers a significant disadvantage that it is difficult to precisely control the dimensions of microchannel because the etching is isotropic processing behavior. Additionally, the etchants used in the chemical etching process also have a negative effect on the natural environment if there is not reasonable recycling procedure. Moreover, lithography technique usually requires complex machining facilities and numerous processing steps, and produce toxic waste. Now this technique is also often limited in high production cost, material choice and channel geometry [19–21]. EDM as a high precision machining technology is employed to fabricate the micro geometry structure such as microchannel, micropore and microneedle with a voltage generator and an electrode. However, low work removal rate and time consuming machining process of EDM become significant obstacle to mass production [22]. In addition, several novel milling methods have been developed to fabricate the microchannel reactors for hydrogen production with different structural constructions. Because of the limit of milling tool, the small dimension microchannel (width below 500 μm) is difficult to be fabricated using this method [23,24].

Interestingly, some novel manufacturing methods were developed to fabricate the different microchannel arrays as the catalyst support in the microreactor for hydrogen production. Kawamura et al. [25] used the photolithography method to fabricate the serpentine microchannel on the glass and silicon substrates to construct a miniaturized methanol reformer for a small PEMFC. Mahabunphachai et al. [26] proposed the internal fluid pressure technique to fabricate the microchannel arrays on thin metallic sheet with the dimensions between 0.46–1.33 mm and 0.15–0.98 mm in width and height, respectively. Recently, Mei et al. [27,28] designed and fabricated a novel microreactor with micro-pin-fin arrays using the micro thixo-forming technology. Both the numerical simulation and methanol steam reforming experiments were adopted to investigate the heat and mass transfer characteristic of the microreactor for hydrogen production.

From above research work, it is found that there are still significant challenges to fabricate the microchannel with low production cost and short machining time. An attractive method to reduce the cost and time for the fabrication of microchannels is laser micro-milling, which can form the good surface quality and accurate cross-sectional shapes. In previous research work, several publications have discussed the general aspects of laser micromachining for microchannel with different dimensions [29–32]. Li et al. [29] fabricated the arbitrary three-dimensional microchannels in the interior of silicon material using an 800 nm femtosecond pulsed laser. The diameter of microchannels could be controlled by varying laser power, scan velocity and focal depth. Kam et al. [30] reported the direct writing of multi-depth microchannel branching networks into a silicon wafer with femtosecond pulses at 200 kHz. The effect of processing speed, machining range with quality surface, and precision on the microchannel branching networks was also investigated. Chung et al. [31] proposed a novel method of foil-assisted CO_2 laser micromachining to fabricate the cross-microchannels in polymethylmethacrylate by significantly diminishing the bulges and the channel's feature sizes. Recently, Darvishi et al. [32] investigated the ultrafast laser machining of tapered microchannel trenches in both hard (soda–lime and borosilicate glasses) and soft (PDMS elastomer) transparent solids. A simple model for microchannel width and depth as a function of processing parameters and threshold fluence was presented. Although several studies on various aspects of laser micromachining process of microchannel have been published, it is easily found that the information on the laser micro-milling process of microchannels as catalyst support for microreactor for hydrogen production is limited [33].

In the present study, the laser micro-milling method was employed to fabricate the microchannel array as catalyst support for microreactors without any post processing. The laser micro-milling process of microchannel on copper sheet was further discussed. Based on the SEM observations, the dependence of surface morphology and geometrical dimension of microchannel on scanning speed, laser output power and number of scans has been investigated in detail. Subsequently, the microchannel array on copper sheet fabricated by the laser micro-milling technique was used as catalyst support in methanol steam reforming microreactor to successfully produce the hydrogen source for fuel cell.

2. Experimental setup

2.1. *Laser micromilling process of microchannel on copper sheet*

The high purity copper sheets (99.99% Cu) with 2 mm thickness were selected as workpiece materials. The schematic of experimental setup for laser micro-milling process is shown in Fig. 1. The system is composed of fiber laser, scanning galvanometer, focusing lens, computer-controlled system, power equipment, CCD camera, LED light and working table. In this study, a prototype pulsed fiber laser (IPG, No: YLP-1-100-20-20-CN, Germany) was used as the fabrication laser. The laser was set to produce 100 ns pulses with the 1064 nm central emission wavelength at a repetition rate of 20 kHz. The nominal output power of laser was 20 W, which was sufficiently higher than the ablation threshold of sample materials. The specifications of characteristic parameters of the used fiber laser system are given in Table 1. The laser output