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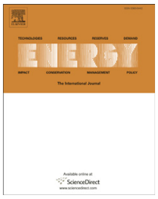

Stainless steel micro fuel cells with enclosed channels by laser additive manufacturing

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ABSTRACT

This study introduces the first steel micro fuel cells with enclosed channel flowfield made by laser additive manufacturing. These are also the first microfluidic devices with enclosed channels made from stainless steel by additive manufacturing. One important benefit of such fabrication methods is ultrafast prototyping, which we made use of in this study to optimize the performance of our fuel cells. The fabrication process consists of preparing a 3D model using a suitable computer-aided design software and then uploading the model file to the laser additive manufacturing machine. This process requires minimal manual intervention. The use of stainless steel as the fabrication material results in extremely durable, robust, chemically and thermally stable devices. Micro fuel cells with three different stainless steel flowfields were fabricated and characterized, two of which with enclosed channels, and one with traditional open grooves. Both enclosed channel flowfield fuel cells produced significantly higher power and current densities compared to the open groove counterpart: the maximum current density obtained was 1.515 A cm^{-2} and maximum power density was 363 mW cm^{-2}.

1. Introduction

Mobile phones, tablets, smart-watches, laptops and other portable electronics are most commonly powered by Li-ion cell batteries, but a push towards higher energy densities and faster charging has led to research in MFCs (micro fuel cells) as an alternative [1,2]. One notable feature of MFCs as microfluidic devices is the need for a current collector, which has to be made from a highly electrically conductive material. Typically, a thin metallic film is deposited on a flowfield fabricated from a poorly conductive or non conductive bulk material such as silicon [3,4,5,6,7], or polymers such as PMMA (poly(methyl methacrylate)) [8,9], SU-8 [10], and PDMS (polydimethylsiloxane) [11,12]. A less common approach is to micromachine the entire flowfield from a highly conductive material, such as e.g. pyrolysed carbon [13], bulk aluminium [14], hydroformed stainless steel sheets [15], and CNC (computer numerical control) machined steel [16]. With the exception of CNC machining [9,16] and laser ablation [6,8], most traditional microfabrication techniques are not well suited for fast prototyping: a testable MFC cannot be directly produced starting from a CAD (computer-aided design) design. In contrast, additive manufacturing technologies require very few steps from design to testable prototype. In an earlier work we presented the fabrication of MFCs using LAM (laser additive manufacturing) of stainless steel [17]. In LAM 3D parts are produced by selective laser beam melting and solidification of consecutive layers of powdered material on top of each other (Fig. 1) [18,19]. LAM allowed us to speedily prepare three different prototypes with high current and power densities, demonstrating the value of the approach.

In the current study the focus is on a different aspect of LAM: the capability of creating enclosed channels, i.e. enclosed cavities, in one step. In microfabrication the typical approach for the creation of such structures is capping of channels by bonding [20] or using sacrificial materials [21,22]. Less common approaches include capping by non-uniform deposition [23], and de Boer et al.'s BCT (Buried Channel Technology) [24]. All these techniques require several microfabrication steps to complete. With LAM, enclosed structures can be easily fabricated in one step, as long as some simple design rules are followed.

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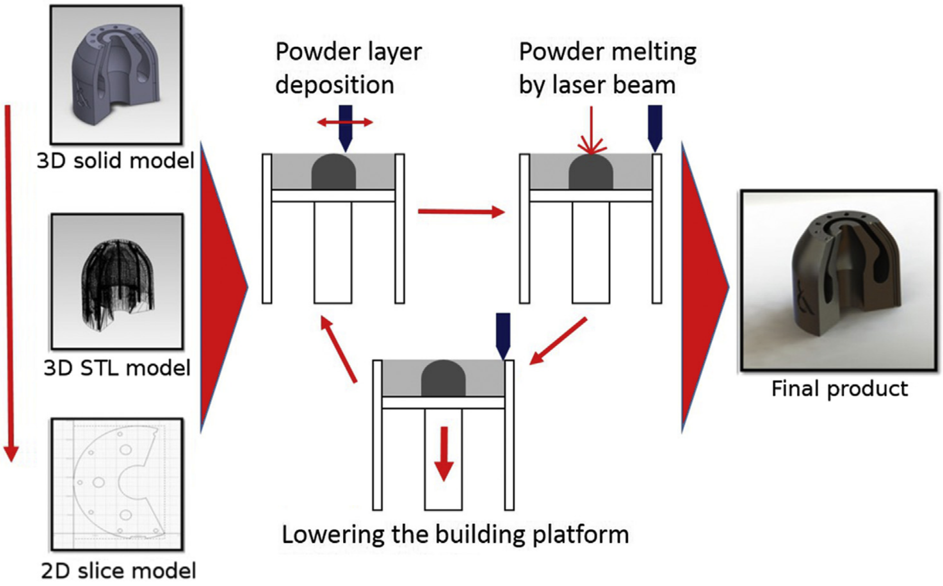

Fig. 1. Diagram describing the LAM (laser additive manufacturing) process.

The motivation for the experiment with enclosed channel flowfields was to test whether the increased contact area between flowfield and GDL (gas diffusion layer) would result in higher fuel cell performance. The increased contact area results from not having traditional grooved flowfields where the channel itself has no electrical contact with the GDL, but instead channels reside inside the flowfield plate. The reactant gases are distributed through apertures connecting the channels and the GDL. Three designs of flowfield plate were fabricated and tested: two with enclosed channels, differing in number of channels, apertures, and aperture sizes, and one with traditional channels, identical to the 2 × 1 cm^2 design presented in Ref. [17]. Both MFCs with enclosed channel flowfields showed considerably better performance compared to traditional grooved flowfield MFCs.

The material for the MFCs is medical grade 316L stainless steel alloy. It is a very hard and tough material with excellent corrosion resistance — properties which allow for repeated experiments with the same devices without significant chemical or mechanical degradation.

2. Experimental

2.1. MFC structure and construction

The construction of the MFCs in this work is similar to the ones in Refs. [14,17,25]: the flowfield plates have a flowfield with either grooves or enclosed channels, and a basin in which a commercial carbon cloth GDL is inserted (Fig. 2). The basin is 200 μm deep, for all the flowfield plate types. All three flowfields have a surface area of 2 × 1 cm^2.

For convenience, the flowfield plates, and MFCs constructed with these flowfield plates, will be referred as follows:

- Type G has 500 μm wide and 1 mm deep grooves, spaced apart at a pitch of 1.5 mm.
- Type E1 has two longitudinal and 5 transversal enclosed channels. There are 23 flowfield apertures with a 0.8 mm diameter per flowfield plate.
- Type E2 has two longitudinal and 7 transversal enclosed channels. There are 35 flowfield apertures with a 0.6 mm diameter per flowfield plate.

Reactant gases (hydrogen or oxygen) are circulated into the flowfield plates through 1 mm diameter inlet holes. The gases are distributed across the GDL through grooves in the case of Type G flowfield plates, and through enclosed channels and flowfield apertures in the case of Type E1 and E2 flowfield plates.

Fig. 3 shows 3D models of the three LAM-fabricated flowfield plates. To help visualize the 3D features, especially the inlet holes, flowfield apertures, and enclosed channels, four different views are presented:

- Isometric view with “X-ray” rendering to show the enclosed channels.
- Top view with cutout lines.
- Bottom view.
- Isometric view of two cutouts — one through an inlet hole, the other along the middle of the flowfield plate.

Both Type E1 and Type E2 have enclosed channels with cross section of 0.72 mm^2 (Fig. 4b).

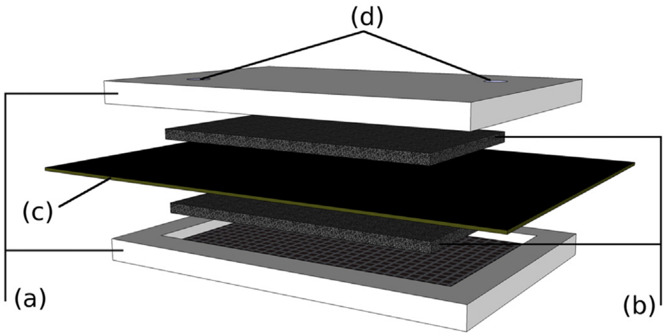

Fig. 2. Exploded view of the construction of MFCs with stainless steel flowfield plates, fabricated by LAM. (a) Flowfield plates with flowfield (either grooves or enclosed channels), and basin that accommodates the GDL. (b) GDL. (c) MEA. (d) Gas inlet holes.