Determination of the Inner Surface Area of 3D Wavelength Scale Structures by Using Angle-resolved Fourier Image Spectroscopy

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The areal energy density of fuel cells and batteries is proportional to the mass loading of the electrochemically active materials. As can be expected, the development of 3D electrodes holds promise for the implementation of highly efficient energy and power capabilities of fuel cells [1] and batteries [2]. Despite the development of some proof-of-concept examples, currently there are no 3D electrodes that simultaneously possess dimensional compatibility, high mass activity, and high electrochemical performance. This problem is hindering successful implementation of energy applications. Hence, successful development of 3D electrodes with all these features is essential for further advancement of energy applications.

This work involves 3D Direct Laser Writing (DLW)-based templating, optical characterization using Fourier Image Spectroscopy (FIS) [3, 4] aiming at fabricating 3D electrodes with a large active surface area. We consider 3D electrodes based on 3D periodic structures with periods in the micrometre range, as they exhibit photonic band structures in the visible to near-infrared wavelength range of light, that can be measured using FIS, as shown in figure 1(a-d). Matching the FIS measurement to simulations allows validating the dimensions and quality of the templates before and after any further post-processing. After determining the dimensions, the surface area can be calculated. Furthermore, to maximize the active surface area of the resulting electrodes for a given volume, optimal fabrication parameters for various 3D periodic structures can be calculated.

To further reduce the size of fabricated templates, thermal annealing can be used [5, 6]. Figure 1(e) demonstrates this based on a 3D diamond lattice-based electrode fabricated through stereolithography combined with a post-processing treatment based on thermal annealing, which resulted in the reduction of the polymer template size by a factor of 3. It has been also shown that the volume of polymer template fabricated through two-photon polymerization DLW (2PP-DLW) can be reduced in a similar way [6]. Accordingly, we are investigating the electrode application of polymer template fabricated using 2PP-DLW combined with thermal annealing to demonstrate 3D electrode fabrication at the nano/micrometre scale.

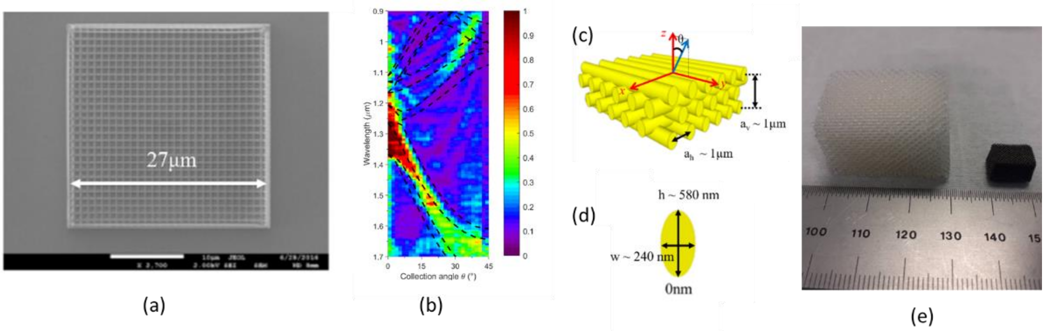

Fig. 1 (a) SEM image of a fabricated polymer woodpile template, (b) Measured angle-resolved reflection spectra of the woodpile structure. Dashed lines indicate the corresponding photonic band structures calculated via the Plane-Wave Expansion method. (c-d) Dimensions of the woodpile that most closely matched the optical measurements based on simulations, (e) A diamond-lattice-like structure before (left) and after (right) thermal annealing.

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