TAILORED AND UNIFORM COATINGS IN MICROCHANNEL APPARATUS

RELATED APPLICATIONS

[0001] In accordance with 35 U.S.C. sect. 119(e), this application claims priority to U.S. Provisional Application No. 60/556,014, filed Mar. 23, 2004.

FIELD OF THE INVENTION

[0002] This invention relates to microchannel apparatus having interior microchannels that have coatings which are applied after the apparatus has been assembled or manufactured to form the interior microchannels.

[0003] Introduction

[0004] In recent years there has been tremendous academic and commercial interest in microchannel devices. This interest has arisen due to the advantages from microtechnology including reduced size, increased productivity, the ability to size systems of any desired capacity (i.e., "number-up" channels), increased heat transfer, and increased mass transfer. A review of some of the work involving microreactors (a subset of microchannel apparatus) has been provided by Gavrilidis et al., "Technology And Applications Of Microengineered Reactors," Trans. IChemE, Vol. 80, Part A, pp. 3-30 (January 2002).

[0005] Microchannel apparatus can be made of a variety of materials including ceramics, plastics, and metals. In many applications, process channels in microchannel apparatus require a coating or coatings over the structural material. The coatings can serve purposes such as absorption, adsorption, physical barrier to the metal wall for purposes of metal passivation for unwanted interactions or depositions, a membrane, and catalysis. In some cases, microchannels are slurry coated or sol coated; for example, an oxide coat applied to a ceramic honeycomb. In some cases, sheets of a material are coated and then assembled and bonded to form a multilayer microchannel device.

[0006] One problem that has been recognized for some time is non-uniform coatings on microchannel walls. For conventional processes, such as dip coating, capillary action results in excess coatings in channel corners. As pointed out by Spencer in U.S. Pat. No. 5,827,577 (filed in November 1996), uneven catalyst coatings result in reduced catalyst performance and thermal shock failure. Spencer addressed this problem by imprinting a catalyst or adsorbent composition onto sheets that may be subsequently rolled into a honeycomb or monolith poluution treating device.

[0007] Zapf et al. in "Detailed Characterization of Various Porous Alumina-Based Catalyst Coatings Within Microchannels and Their Testing for Methanol Steam Reforming," Trans. IChemE, pp 721-729 (August 2003) remarked that literature reports so far showed non-uniform coating profiles in both semi-circular and rectangular channels. In their own studies on alumina washcoats onto microchannels etched into an open-faced plate, they reported a thickness of an alumina washcoating that was 20 μm in the center and 70 μm near the channel walls or corners for microchannels that were 500 and 750 μm wide. The smallest differences in washcoat thickness were observed for shallow channels with a depth of 70 μm—10-15 μm at the channel center and 15-20 μm at the channel wall.

[0008] Wan et al. in "1-Pentene Epoxidation in Titanium Silicate-1 Microchannel Reactor: Experiments and Modeling," Trans. IChemE, pp 1-7 (August 2003) reported a technique for selectively depositing zeolite layers into microchannels. This technique required etching a silicon substrate, followed by functionalization of the etched surface, seeding and zeolite growth on the prepared surfaces.

[0009] Bednarova et al. in "Preferential oxidation of CO in a microreactor with a single channel," Am. Chem. Soc., Div. Fuel Chem. 2003, 48(2), showed an open-face microreactor with an alumina/Pt layer formed by a sol-gel technique. Although the authors described the coating as "fairly uniform" the photograph of the cross-section appeared to show substantially non-uniform coatings.

[0010] Since one aspect of the present invention includes aluminide coatings, reference can be made to early work described by LaCroix in U.S. Pat. No. 3,944,505. This patent describes a catalytic device made of a stack of expanded metal sheets (such as Inconel). The metal sheets carry a layer of a nickel or cobalt aluminide and a layer of alpha alumina on the aluminide, and a catalytic surface on the aluminide. LaCroix did not describe how the aluminide layer was formed on the sheets, nor did LaCroix provide any data describing the aluminide layer.

[0011] Methods of forming aluminide coatings are well known and have been utilized commercially for coating certain jet engine parts. Methods of making aluminide coatings from aluminum halides are described in, for example, U.S. Pats. Nos. 3,486,927 and 6,332,926.

[0012] There have been attempts to apply aluminide coatings on interior channels of gas turbine airfoils. Rigney et al. in U.S. Pat. No. 6,283,714 reported coating internal cooling passages of turbine blades with an aluminide coating using a slurry/pack process. Rigney et al. also stated that an aluminum halide gas could be passed through the cooling passages at high temperature so that an aluminide coating about 0.002 inch (50 μm) thick may be deposited in about 4 to 8 hours. Pfaendter et al. in U.S. Pat. No. 6,332,926 also suggests flowing an aluminum-coating precursor to deposit aluminum onto an internal airfoil surface.

[0013] Howard et al. in U.S. Pat. No. 5,928,725 entitled "Method and Apparatus for Gas Phase Coating Complex Internal Surfaces of Hollow Articles," reviewed prior art methods of gas phase coating for coating internal surfaces but remarked that the prior art methods were ineffective for coating multiple gas passages of modern airfoils and result in non-uniform internal coatings. In the process described in this patent, the coating gas flow rate is controlled to a different rate into at least two channels. Howard et al. state that a coating mixture including aluminum powder, aluminum oxide and aluminum flouride could be heated to deliver a coating gas. This improved method was reported to result in an aluminide coating thickness of 1.5 mils±1.0 mil.

[0014] Folta et al. in U.S. Pat. No. 6,562,404 described a technique for coating silicon microflow devices with a conformal layer of silicon nitride (SiN). This technique uses vacuum chemical vapor deposition (CVD) of dichlorosilane and ammonia at temperatures of 775-875° C. to produce crack-free SiN films with thicknesses of 1-2 μm. Folta et al. Claimed that this technique had "the ability to uniformly coat deeply recessed cavities with aspect ratios of 40:1 or