DESCRIPTION OF THE INVENTION

[0054] Microchannel Apparatus

[0055] Microchannel reactors are characterized by the presence of at least one reaction channel having at least one dimension (wall-to-wall, not counting catalyst) of 1.0 cm or less, preferably 2.0 mm or less (in some embodiments about 1.0 mm or less) and greater than 100 nm (preferably greater than 1 μm), and in some embodiments 50 to 500 μm. A reaction channel is a channel containing a catalyst. Microchannel apparatus is similarly characterized, except that a catalyst-containing reaction channel is not required. Both height and width are substantially perpendicular to the direction of flow of reactants through the reactor. Microchannels are also defined by the presence of at least one inlet that is distinct from at least one outlet—microchannels are not merely channels through zeolites or mesoporous materials. The height and/or width of a reaction microchannel is preferably about 2 mm or less, and more preferably 1 mm or less. The length of a reaction channel is typically longer. Preferably, the length of a reaction channel is greater than 1 cm, in some embodiments greater than 50 cm, in some embodiments greater than 20 cm, and in some embodiments in the range of 1 to 100 cm. The sides of a microchannel are defined by reaction channel walls. These walls are preferably made of a hard material such as a ceramic, an iron based alloy such as steel, or a Ni-, Co- or Fe-based superalloy such as monel. The choice of material for the walls of the reaction channel may depend on the reaction for which the reactor is intended. In some embodiments, the reaction chamber walls are comprised of a stainless steel or Inconel® which is durable and has good thermal conductivity. The alloys should be low in sulfer, and in some embodiments are subjected to a desulferization treatment prior to formation of an aluminide. Typically, reaction channel walls are formed of the material that provides the primary structural support for the microchannel apparatus. The microchannel apparatus can be made by known methods (except for the coatings and treatments described herein), and in some preferred embodiments are made by laminating interleaved plates (also known as "shims"), and preferably where shims designed for reaction channels are interleaved with shims designed for heat exchange. Of course, as is conventionally known, "reactors' do not include jet engine parts. In preferred embodiments, microchannel apparatus does not include jet engine parts. Some microchannel apparatus includes at least 10 layers laminated in a device, where each of these layers contain at least 10 channels; the device may contain other layers with less channels.

[0056] **FIG. 1** is a schematic and simplified view of one embodiment of a microchannel reactor in which reactant feed passes through a reaction microchannel (bottom) while coolant (in a cross-flow arrangement) flows through an adjacent heat exchanger (top). Microchannel reactors preferably include a plurality of microchannel reaction channels and a plurality of adjacent heat exchange microchannels. The plurality of microchannel reaction channels may contain, for example, 2, 10, 100, 1000 or more channels. In preferred embodiments, the microchannels are arranged in parallel arrays of planar microchannels, for example, at least 3 arrays of planar microchannels. In some preferred embodiments, multiple microchannel inlets are connected to a common header and/or multiple microchannel outlets are connected to a common footer. During operation, the heat exchange microchannels (if present) contain flowing heating and/or cooling fluids. Non-limiting examples of this type of known reactor usable in the present invention include those of the microcomponent sheet architecture variety (for example, a laminate with microchannels) exemplified in U.S. Pat. Nos. 6,200,536 and 6,219,973 (both of which are hereby incorporated by reference). Performance advantages in the use of this type of reactor architecture for the purposes of the present invention include their relatively large heat and mass transfer rates, and the substantial absence of any explosive limits. Microchannel reactors can combine the benefits of good heat and mass transfer, excellent control of temperature, residence time and minimization of by-products. Pressure drops can be low, allowing high throughput and the catalyst can be fixed in a very accessible form within the channels eliminating the need for separation. Furthermore, use of microchannel reactors can achieve better temperature control, and maintain a relatively more isothermal profile, compared to conventional systems. In some embodiments, the reaction microchannel (or microchannels) contains a bulk flow path. The term "bulk flow path" refers to an open path (contiguous bulk flow region) within the reaction chamber. A contiguous bulk flow region allows rapid fluid flow through the reaction chamber without large pressure drops. In some preferred embodiments there is laminar flow in the bulk flow region. Bulk flow regions within each reaction channel preferably have a cross-sectional area of 5×10^{-8} to 1×10^{-2} m^2, more preferably 5×10^{-7} to 1×10^{-4} m^2. The bulk flow regions preferably comprise at least 5%, more preferably at least 50% and in some embodiments, at least 90% of either 1) the internal volume of the reaction chamber, or 2) a cross-section of the reaction channel.

[0057] In many preferred embodiments, the microchannel apparatus contains multiple microchannels, preferably groups of at least 5, more preferably at least 10, parallel channels that are connected in a common manifold that is integral to the device (not a subsequnetly-attached tube) where the common manifold includes a feature or features that tend to equalize flow through the channels connected to the manifold. Examples of such manifolds are described in U.S. patent application Ser. No. 10/695,400, filed Oct. 27, 2003 which is incorporated herein as if reproduced in full below. In this context, "parallel" does not necessarily mean straight, rather that the channels conform to each other. In some preferred embodiments, a microchannel device includes at least three groups of parallel microchannels wherein the channel within each group is connected to a common manifold (for example, 4 groups of microchannels and 4 manifolds) and preferably where each common manifold includes a feature or features that tend to equalize flow through the channels connected to the manifold. An aluminide coating can be formed in a group of connected microchannels by passing an aluminum-containing gas into a manifold, typically, the manifold will also be coated.

[0058] Heat exchange fluids may flow through heat transfer microchannels adjacent to process channels (preferably reaction microchannels), and can be gases or liquids and may include steam, liquid metals, oils, or any other known heat exchange fluids—the system can be optimized to have a phase change in the heat exchanger. In some preferred embodiments, multiple heat exchange layers are interleaved with multiple reaction microchannels. For example, at least 10 heat exchangers interleaved with at least 10 reaction