LAMINAR MIXING APPARATUS AND METHODS

RELATED APPLICATIONS

[0001] This application is a continuation of International Application No. PCT/US02/23462, filed Jul. 24, 2002, which was published under PCT Article 21(2) in English, and claims priority to U.S. Application Ser. No. 60/308,206, filed Jul. 27, 2001. Both application are incorporated herein by reference.

GOVERNMENT FUNDING

[0002] This invention was sponsored by the National Science Foundation Grant Numbers ECS-9729405 and ECS-0004030. The government has certain rights in this invention.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

[0004] The present invention relates to mixing laminarly flowing fluids and, more particularly, to low Reynolds number mixing apparatus and to methods of use thereof.

[0005] 2. Description of Related Art

[0006] Mixers are known in the art for mixing materials. These mixers may be useful in various applications such as mixing chemicals in industrial processes, mixing multi-part curing systems in adhesives, foams and molding compounds, mixing fuels and gases for combustion, mixing air into water for sewerage treatment, or wherever mixing needs to be accomplished.

[0007] There are generally two types of fluid flow, laminar flow and turbulent flow. In laminar flow, the fluid flows in smooth layers or lamina. This occurs when adjacent fluid layers slide smoothly over one another with mixing between layers or lamina occurring predominantly on a molecular level by diffusion. Turbulent flow is characterized by fluctuations of the velocity of the fluid in both space and time. Mixing of two or more substances in turbulent flow conditions generally proceeds faster than under laminar flow conditions.

[0008] The viscosity, the flow rate, and the density of the fluid along with the diameter of the flow path dictates the type of fluid flow. The more viscous two materials are or the smaller the cross-sectional dimension of the channel in which they flow, the higher the flow rate required in order to create a turbulent flow. These variables can be combined into a dimensionless parameter to characterize the flow called the Reynolds number according to

$$Re = \frac{D\rho v}{\mu}$$

[0009] where D is the characteristic dimension of the path, ρ is the density of the fluid, v is the fluid flow velocity, and μ is the viscosity of the fluid. Flows are typically laminar for Re less than 2300 and turbulent for Re less than 2300.

SUMMARY OF THE INVENTION

[0010] In one embodiment, the present invention relates to an article. The article comprises a microfluidic channel defined therein and designed to have fluid flow therethrough in a principal direction. The microfluidic channel includes a channel surface having at least one groove or protrusion defined therein. The at least one groove or protrusion has a first orientation that forms an angle relative to the principal direction.

[0011] In another embodiment, the present invention provides an article comprising a microfluidic channel constructed and arranged to have a fluid flowing therethrough while creating a transverse flow component in the fluid.

[0012] In another embodiment, the present invention relates to an article comprising a structure having a channel defined therein, the channel designed to have a fluid flowing therethrough in a principal direction, the channel including a channel surface having a plurality of chevron-shaped grooves or protrusions formed in at least a portion of the channel surface so that each chevron-shaped groove or protrusion has an apex that defines an angle.

[0013] In yet another embodiment, the present invention relates to a structure. The structure comprises a first channel having a width that is less than about 1000 μm, a second channel having a width that is less than about 1000 μm and a third channel having a principal direction and a width that is less than about 1000 μm. The third channel connects the first and second channels and comprises channel surfaces having grooves or protrusions defined therein. The grooves or protrusions are oriented at an angle relative to the principal direction.

[0014] In another embodiment, the present invention relates to a method for dispersing a material in a fluid. The method comprises the steps of providing an article having a channel designed to have fluid flow therethrough in a principal direction, the channel including a channel surface having at least one groove or protrusion therein that traverses at least a portion of the channel surface, at least one groove or protrusion oriented at an angle relative to the principal direction and causing the fluid in the channel to flow laminarly along the principal direction.

[0015] In another embodiment, the present invention is directed to a method. The method comprises the steps of causing a first fluid to flow in a channel at a Reynolds number that is less than about 100, causing a second fluid to flow in the channel at a Reynolds number that is less than about 100 and creating a transverse flow component in the first and the second fluids to promote mixing between the first and second fluids.

[0016] In yet another embodiment, the present invention is directed to a method for forming a microfluidic article. The method comprises the steps comprising forming a first topological feature that has a smallest dimension that is less than about 1000 μm on a surface of a mold substrate, forming a second topological feature on the first topological feature to form a mold master, the second topological feature characterized by a length that traverses at least a portion of a section of the first topological feature, placing a hardenable material on the surface, hardening the material thereby creating a molded article having a microfluidic channel shaped from the first topological feature and at least one groove or protrusion shaped from the second topological feature and removing the microfluidic article from the mold master.