shaped structures typically have at least one apex, which is formed by lines intersecting at an angle. The term "chevron-shape" is meant to represent a structure having a V-shape or zigzag shape. And, as used herein, the term "chevron-shaped" is meant to include structures formed by intersecting linear and non-linear lines as well as symmetrical and asymmetrical V-shapes and structures having multiple intersections.

[0042] In one embodiment, the mixing apparatus comprises herringbone-shaped or chevron-shaped features that are asymmetric with respect to a lengthwise axis of the channel forming the mixing apparatus. In another embodiment, the asymmetry of the chevron-shaped features vary in alternating or in other predetermined fashion. For example, with reference to **FIG. 5**, the asymmetry of chevron-shaped grooves in the first set differs from that of the adjacent set.

[0043] As used, herein, a pair of sets forms a cycle of the mixing apparatus. The term "cycle" is refers to a plurality of sets that are sufficient to produce a spiral flow component. Thus, in one embodiment, one cycle refers to a first set of similarly grooves and a second set of similarly shaped grooves. A set of cycles may comprise a plurality of cycles, each cycle comprising sets of shaped features and each cycle may be geometrically distinguishable from another cycle. For example, a set may comprise a group of chevron-shaped grooves defining a first apex group that are similarly shaped and a second set of chevron-shaped grooves defining a second apex group that are similarly shaped, the second apex group are "offset" from the first apex group such that the apex is displaced from the first group relative to an axis, e.g., the axis along the principal direction. Such a design can be characterized by, among others, the degree of asymmetry as measured by the fraction of the width of the channel that is spanned by the wider branch of the chevron-shaped grooves and the amplitude of the rotation of the fluid, as measured by θ and shown in **FIG. 4*b***, that is induced by the chevron-shaped structures. The amplitude of the rotation is influenced by the geometry of the undulations and the number of undulations per set or half cycle.

[0044] Thus, in another embodiment, the mixing apparatus comprises a first channel disposed in a structure having a width that is less than about 5000 μm, a second channel also disposed in the structure and also having a width that is less than about 5000 μm and a third channel with a principal direction and having a width that is less than about 5000 μm that connects the first and second channels and comprising channel surfaces with grooves, which are oriented at an angle relative to the principal direction. However, those of ordinary skill practicing the invention may readily recognize that the structures described herein may be used to effect mixing in any non-turbulent flow system. Thus, a system that may have a relatively large characteristic dimension may nonetheless be non-turbulent if the fluid flowing therein the fluid flowing adjacent to the features that create a transverse flow component are non-turbulent. For example, mixing may be effected by creating a transverse flow component, with a use of grooves, in a fluid flowing on a surface that extends essentially infinitely in two dimensions. Notably, the fluid may be flowing non-turbulently adjacent to the grooves but may be flowing turbulently away from the surface. Thus, the invention may be used in a surface or a mixing apparatus regardless of the dimension of the channel.

[0045] The staggered herringbone mixing apparatus based on patterned topography on the surface of microchannels can offer a general solution to the problem of mixing fluids in microfluidic systems. The simplicity of its design allows it to be easily integrated into microfluidic structures with standard microfabrication techniques. Such a mixing apparatus can operate over a wide range of Re, specifically, all values less than about 100.

[0046] Substrate **12** can be formed from any suitable material that can used to create structures **16** and performing the desired process operation. Substrate **12** can be formed of a polymeric material such as a random or block polymeric or copolymeric material; suitable polymeric materials include polyurethane, polyamide, polycarbonate, polyacetylene, polysiloxane, polymethylmethacrylate, polyester, polyether, polyethylene terephthalate and/or blends or combinations thereof. Substrate **12** can also be a ferrous, non-ferrous, transition or precious metal such as steel, platinum, gold and/or alloys or combinations thereof. Substrate **12** can be formed of a semiconductor material such as silicon and gallium arsenide including nitrides and oxides formed thereof. The selection of materials suitable to create structures and perform the desired process operation can be performed by those of ordinary skill practicing the field.

[0047] Systems of the present invention can be prepared using soft lithographic techniques. One such technique is discussed by McDonald et al. in *Electrophoresis* 21, 27-40 (2000), which is incorporated in its entirety. Master structures are typically made with two step photolithography, which generally involves preparing a first photolithographic layer defining a positive image of the channel or mixing apparatus and a second photolithographic layer defining a positive image of the pattern of grooves or undulation. The first photolithographic layer can be used as a positive image of the channel. The second layer can be used as a positive image of the pattern of undulations. This second pattern is typically aligned to lie on top of the channel using a mask aligner. The master structures can then used as molds to create a substrate made from polydimethylsiloxane (PDMS).

[0048] To close the molded channel, the PDMS substrates are typically exposed to plasma for one minute and can then be sealed with a glass cover slip. The thickness of the cover slip is typically selected to be optically compatible with the oil immersion objectives of the confocal microscope. For example, a No. 1 glass cover slip can be used with a XX Leica confocal microscope with a 40×/1.0 n.a. objective. It should be understood that other techniques can also be used to form systems of the present invention.

[0049] The functions and advantages of these and other embodiments of the present invention can be further understood from the examples below. The following examples are intended to illustrate the benefits of the present invention, but do not exemplify the full scope of the invention.

EXAMPLE 1

[0050] This example, with reference to **FIGS. 4*a*-*c***, discusses one embodiment of the present invention and is directed to mixing fluids in a mixing apparatus. The broad dark lines, shown in **FIG. 4*a***, represent undulations in the channel surface. A sequential pair of grooves form one cycle. The grooves were oriented at a 45-degree angle relative to the principal direction. Mixing apparatus **32** was