surface **14** of substrate **12**, a source **20** at a first position **22** that can provide a fluid **24** flowing in channel **18** and a sink **26** at a second position **28** wherein fluid **24** is received.

[**0034**] In another aspect, the present invention functions, in part, by increasing the effective exposed or interfacial area to promote diffusion of components between distinct volumes of the flowing fluid. That is, the present invention, in one embodiment, promotes mixing by diffusion by diverting a portion of the flowing fluid as, for example, by creating a transverse flow component in the flowing fluid. The transverse flow component may create a "folding effect" so that the effective exposed area through which diffusion of molecular species can occur is increased or, in another sense, the distance over which diffusion must act to eliminate concentration variations is decreased. Such an effect may reduce the rate of dispersion along the flow by carrying unit volumes of the fluid between fast and slow moving regions. In net effect, i.e., as the fluid progresses through the mixing apparatus, the mixing of the fluid or fluids is increased as the diffusion area is increased and, consequently, the time required to achieve mixing to a desired homogeneity is reduced. The transverse flow component may be viewed, analogously, to the effect created by turbulent flow wherein localized eddy currents are created as a consequence thereof. In another aspect, the transverse flow component can be viewed as stretching the volumes of the fluid at an exponential rate as the fluid is "wound" helically along the principal direction of the flow.

[**0035**] The present invention can be used in laminarly flowing fluids. Thus, as described below, the mixing apparatus and methods thereof are particularly suitable to mix a fluid flowing in the micro-regime. As used herein, the term "microchannel" refers to a channel that has a characteristic dimension, i.e., a width or a depth, that is less than about 1000 microns ($\mu$m). System **10** can be used to mix a fluid or fluids in a microfluidic system to significantly reduce the Taylor dispersion along the principal direction. The present invention may be used advantageously in microfluidic systems wherein the laminar flow is particularly predominant. Fluids flowing in such systems are typically characterized as laminar Poiseuille flows with low Reynolds numbers. As described further below, the mixing apparatus can be designed to create a transverse flow component within such flows that are non-turbulent, preferably with Re having a Reynolds number that is less than about 2000, preferably, less than 100, more preferably, less than about 12, and even more preferably, less than 5.

[**0036**] Thus, in one embodiment, grooves or protrusions can be oriented in a variety of configurations or combinations to effect transverse flow components of the fluid or fluids flowing therethrough that is independent of Reynolds number or as Reynolds number goes to zero.

[**0037**] The present invention, as embodied in the schematic illustration of **FIG. 1**, can be used in a system wherein a desired process operation may be carried out including, but not limited to, flowing a fluid, facilitating a chemical reaction, dissolving a substance in a medium, depositing or precipitating a material on a surface, mixing a fluid or fluids to achieve homogeneity and exposing a first material to a second material. For purposes of illustration, a system **10**, as shown in **FIG. 1**, will be described with respect to a flowing fluid. As used herein, fluid can refer to a gas or a liquid.

[**0038**] According to one embodiment, channel **18** can be formed as a mixing apparatus **32** to facilitate mixing a fluid or fluids flowing therethrough. As schematically illustrated in the embodiment of **FIG. 2***a*, channel **18** comprises a mixing apparatus **32** having a rectangular cross-section with a width and a depth or height. Grooves, undulation or protrusion features **34** are formed on at least one channel surface **30**. Fluid **24** flowing in channel **18** has a principal direction, indicated by reference **36**, along the lengthwise direction of the channel. In other embodiments, the microfluidic channel can have a variety of cross-sectional shapes including, but not limited to, rectangular, circular and elliptical.

[**0039**] In some embodiments, the groove is oriented to form an angle relative to the principal direction. Grooves **34** on channel surface **30** are constructed and arranged to create an anisotropic response to an applied pressure gradient thereby producing at least one three-dimensional flowpath such as transverse flow component in fluid **24** flowing in channel **18**. Grooves **34** can be formed as undulations that provide reduced flowing resistance along the valleys **40** of grooves **34**. That is, fluid near channel surface **30** having groove **34** is exposed to reduced flow resistance at or near the valleys **40** creating a transverse flow component **42**. As the fluid flows further along principal direction **36**, transverse flow components **42** are further generated or increase in magnitude through additional grooves **32** defined along channel surface **30**. The resultant effect creates a circulating or helical flow path **44**.

[**0040**] Grooves **34** typically have a width and a height that is less than the width and height of mixing apparatus **32** and can be arranged periodically along the lengthwise direction of mixing apparatus **32**. As shown in the schematic illustration of **FIG. 3**, grooves **34**, defined on channel surface **30** of mixing apparatus **32**, can have a variety of configurations and combinations. That is, in one embodiment, grooves **34** can be oriented at an angle **38** and can extend substantially or partially across the cross-section of mixing apparatus **32**. Further, it can be seen that those of ordinary skill may recognize that grooves **34** can have a variety of geometrical cross-sections including, but not limited to rectangular, circular and parabolic. Grooves or protrusions **34** can be oriented in a variety of configurations or combinations to effect transverse flow components of the fluid or fluids flowing therethrough that is independent of Reynolds number or as Reynolds number goes to zero.

[**0041**] In another embodiment, grooves **34** can be arranged as a set of grooves, wherein each groove is arranged periodically as shown in **FIGS. 3-5**. Thus, in one embodiment, the mixing apparatus can comprise at least one set, preferably at least two sets and more preferably, a plurality of sets wherein each set comprises a plurality of grooves arranged periodically therein. In another embodiment, each set comprises a periodic arrangement of grooves that are offset from each other such that at least one set is at least partially coextensive with at least another set. In another embodiment, the mixing apparatus comprises a set comprising a plurality of grooves having various configurations. Thus, as illustrated in **FIG. 3**, the grooves may be oriented at an angle relative to the principal direction, may be offset, traverse at least a portion of the cross-section of the mixing apparatus, may be periodically arranged to form a set or a repeating cycle and may have chevron shapes. Chevron-