a microfluidic article with a rectangular cross-section, which was about 200 μm wide and comprised a plurality of fluid inlets **46**, **48** and **50**, a plurality of sets **52** of grooves comprised a cycle, each set with at least one groove **34** arranged periodically along the principal direction. Fluids **54**, **56**, and **58** were introduced through inlets **46**, **48** and **50**, respectively wherein fluid **56** is comprised a fluorescent dye. As the fluids flowed laminarly at a Reynolds number that is less than about 100, a transverse flow component **42** was created in the aggregated fluid in mixing apparatus **32** as schematically depicted in **FIG. 4***b* and as shown in the copy of a micrograph in FIG. **4***c*. The lighter portions represent the fluorescent dye introduced in fluid **56**. This example showed that the grooves in the mixing apparatus can create transverse flow components in a fluid having a Reynolds number that is less than about 100.

EXAMPLE 2

[0051] This example, with reference to **FIGS. 5 and 6***a-c*, discusses another embodiment of the present invention and directed to mixing fluids in a mixing apparatus, specifically, a staggered herringbone mixing apparatus having chevron-shaped grooves. The broad dark lines, shown in **FIG. 5**, represent the chevron-shaped 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. The mixing apparatus was a microfluidic article with a rectangular cross-section, which was about 200 μm wide by 100 μm tall and comprised a plurality of fluid inlets **48** and **50**, a plurality of sets **52** of 50 μm×50 μm rectangular chevron-shaped grooves comprised a cycle, each set with six chevron-shaped groove **34** arranged periodically along the principal direction. The sets were disposed from each other such that the loci of apex of one set was offset from the loci of apex of an adjacent set. Fluids **56** and **58** were introduced through inlets **48** and **50** respectively from their respective reservoirs (not shown). Fluid **56** comprised a fluid, poly(ethylenimine), MW 750,000, fluorescently labeled with 1% FITC in 0.1 wt. % solution while fluid **58** comprised the same solution without FITC. The fluids were pumped through the mixing apparatus at a velocity of about 2.7 cm/s by applying a constant pressure on each fluid reservoir with compressed air. The corresponding Reynolds number was determined to be about 4×10^{-2} and the Péclet number was determined to be about $3.3\times10^{+4}$.

[0052] **FIGS. 6***a-f* are copies of micrographs of vertical cross-sections along the mixing apparatus made using a XX Leica confocal microscope with a 40×/1.0 n.a. objective. These show the distribution of the fluorescent molecules before the first cycle (**FIG. 6***a*), and progressively after the first (**FIG. 6***b*), second (**FIG. 6***c*), fourth (**FIG. 6***d*), eight (**FIG. 6***e*) and sixteenth cycles (**FIG. 6***f*). **FIGS. 6***b-f* shows that generation of a transverse flow components (depicted by the lighter portions) in the fluid as the fluid flows through multiple cycles. Notably, the fluid appears homogeneous after the sixteenth cycle. Thus, this example shows that a mixing apparatus having chevron-shaped grooves can be used to mix fluids flowing at very low Reynolds numbers.

EXAMPLE 3

[0053] In this example, the efficiency of mixing was evaluated. Four fluids were prepared with fluorescent pigment similar to the fluids described in Example 2. The fluids were introduced under varying conditions into a mixing apparatus. The fluids flowed with a Reynolds number that was less than about 7.5 and, respectively, with Péclet numbers of 1.6×10^2 (circle), 1.9×10^2 (square), 7.4×10^3 (triangle) and 3.3×10^4 (diamond). Péclet number is the product of the Reynolds and Prandtl numbers. The latter is the viscosity, μ, of a fluid divided by its molecular diffusivity. Thus, the Péclet number is

$$Pe = \frac{Uh}{D}$$

[0054] where U is the average velocity, h is the height of the channel and D is the diffusivity of the diffusing material in the medium.

[0055] Fluorescence intensity was found to be proportional to the concentration of fluorescent molecules and accordingly, mixing efficiency was characterized as the variation of intensity of the fluorescence. Stated another way, as the degree of mixing increases, the variation measured as the standard deviation of fluorescent intensity approaches zero. **FIG. 7** is a chart showing the standard of deviation of intensity relative to the number of cycles for fluids having various Péclet numbers. As expected, a fluid with a lower Péclet number required less mixing cycles than a fluid with a higher Péclet number because diffusion was the predominant mechanism of mixing. The standard deviation approached 20, not zero, because, it is believed, of optical effects, shadows in the field of view of the microscope, and the noise of the photodetector.

[0056] The example shows that the number of mixing cycles that are required for total mixing grows slowly with Péclet number but that the mixing apparatus according to the present invention can be used to efficiently mix laminarly flowing fluids. The inset shows that the number of cycles required for total mixing is linearly proportional to log(Pe).

EXAMPLE 4

[0057] This example shows the reduction of axial dispersion (the spreading of a plug of miscible solution along the principal direction of the flow) in a mixing apparatus according to one embodiment of the present invention. Two channels having chevron-shaped undulations, each 200 μm×70 μm×20 cm, were produced as shown schematically in **FIG. 8**. The top mixing channel had ten mixing cycles near the entrance while the bottom had mixing cycles substantially throughout its length. Steady streams of alkaline phosphatase (AP) and fluorocien diphosphate (FdP) were introduced into each mixing channel. AP reacted as in came in contact with FdP to produce a fluorescent molecule, fluorocien. The Péclet number was determined to be less than about 1.7×10^4.

[0058] The insets are copies of confocal images of the cross-section of the mixing channel. Specifically, the left insets are copies of confocal images after ten mixing cycles while the right insets, measured about 16 cm downstream, show the effect without (top) mixing and with (bottom) continuous mixing (at about 100 mixing cycles). As shown in the contrasting images, the fluid that is continuously mixed (bottom) was more homogeneous than the fluid that