bulk flow channel) may be used only to create additional surface area to deposit a catalyst, wherein flow rotates in the first level of surface feature and diffuses molecularly into the second or more sublayers to promote reaction. Three-dimensional features may be made via metal casting or other processes where varying patterns can not be broken into discrete planes as if stacked on top of each other. Three-dimensionally varying surface features may be found adjacent to the bulk flow channel where the features have different depths, shapes, and locations accompanied by sub-features with patterns of varying depths, shapes and locations. The inventive structures may be advantageous for chemical reactions requiring additional surface area for catalyst deposition or for chemical separations such as distillation.

[0113] FIG. **4***b* illustrates a three dimensional surface feature structure, where recessed chevrons are found at the interface adjacent of the bulk flow microchannel and beneath the chevrons are a series of 3-D structures (pale lines) that connect to the features adjacent to the bulk flow path but are made from structures of assorted shapes, depths, and locations. It may be further advantageous to create sublayer passages that do not directly fall beneath an open surface feature that is adjacent to the bulk flow microchannel but rather connect through one or more tortuous 2-D or 3-D passages. This approach may be advantageous for creating tailored residence time distributions in reactors, where it may be desirable to have a wider versus more narrow residence time distribution.

[0114] FIG. **2***a* shows surface features with variable patterns (axially) and variable depths (laterally). The pattern of surface features shown in FIG. **2***a* introduces a spatially varying depth of surface features either within an individual surface feature and or between any two surface features within a surface feature section. This may be particularly advantageous for some applications where changing the depth of the surface feature within a surface feature may create more flow rotation or vorticity such that the external mass transfer resistance between fluids or from a fluid to a catalyst wall is significantly reduced.

[0115] The pattern of FIG. **2***b* may be particularly advantageous as an underlayer surface pattern that sits beneath at least one or more other surface pattern sheets to increase the available surface area for catalyst or a mass exchange agent. The pattern of FIG. **2***c* illustrates surface features with cross-hatched features.

[0116] The pattern of FIG. **2***d* introduces both angled features and a horizontal feature. The feature geometry may vary along the length of the process channel. This design may be particularly advantageous as an underlayer surface pattern sheet that is used to both hold more catalyst or mass exchange agent while also creating more depth to angled features that may preferentially sit adjacent to this sheet. The second and angled sheet is adjacent to the flow path and induces flow rotation. The varying depths of angled features may create more turbulence or apparent turbulence in the flow paths.

[0117] Preferred ranges for surface feature depth are less than 2 mm, more preferrably less than 1 mm, and in some embodiments from 0.01 mm to 0.5 mm. A preferred range for the lateral width of the surface feature is sufficient to nearly span the microchannel width (as shown in the herringbone designs), but in some embodiments (such as the fill features) can span 60% or less, and in some embodiments 40% or less, and in some embodiments, about 10% to about 50% of the microchannel width. In preferred embodiments, at least one angle of the surface feature pattern is oriented at an angle of 10°, preferably 30°, or more with respect to microchannel width (90° is parallel to length direction and 0° is parallel to width direction). Lateral width is measured in the same direction as microchannel width.

[0118] The lateral width of the surface feature is preferably 0.05 mm to 100 cm, in some embodiments in the range of 0.5 mm to 5 cm, and in some embodiments 1 to 2 cm.

[0119] Recessed features on opposite faces of a microchannel can be coordinated for dramatically increased levels of heat and mass transport. A substantially diagonal (relative to length or the direction of flow) flow path recessed into the wall of a microchannel is a basic building block used in the present invention to promote flow patterns which can be coordinated on opposite walls to provide a surprisingly superior mixing relative to the same or similar patterns on only a single wall. Because of the substantially diagonal nature of the recessed flow path, the velocity in the recessed channel contains a significant component parallel or angled to the mean direction of bulk flow in the microchannel, thus inducing significant flow in the recessed channel. However, when the diagonal flow paths in the recessed channel on one major face of a microchannel are properly coordinated with those on the opposite face, flow perpendicular to the mean bulk flow direction within the open microchannel can be very effectively promoted. Perpendicular flow is especially advantageous for reducing the external mass transport or heat transport limitations that are found with laminar flow microchannels. Specifically, the advection rate of flow perpendicular to the bulk flow direction brings fluids to the microchannel wall at a rate that is at least 2×, or 5×, or 10× or more greater than the rate of mass transport from diffusion alone. As such, reactions that are driven by catalysts affixed to the microchannel walls or to a support structure adjacent to a microchannel wall will have a higher surface concentration of reactants and thus a higher overall reaction rate. Heat transfer is also advantaged by perpendicular advection and velocity vectors as this increases the surface heat transfer coefficient and reduces the boundary layer limitation on fluid temperature. This induced perpendicular flow can be promoted in some preferred embodiments by: (1) strategically placing features which tend to pull flow into the recessed channels on one face in a location relative to those on the opposite face which tend to pull flow into the recessed channels on the opposite face (i.e. cis configuration), (2) maintaining the opposing walls sufficiently close together (keeping the microchannel gap sufficiently narrow) to allow interaction between the opposing faces.

[0120] In general, if lateral mixing is desired (across the width of the channel), the features on opposite faces should promote flow with a substantially diagonal component in the plane perpendicular to the direction of the mean bulk flow. In such a case, the features should be coordinated to do this. The substantially diagonal features recessed in the wall of the open microchannel have a component of length in the mean bulk flow direction which is preferably equal to or greater than, and more preferably at least two times the component in the lateral direction (the channel width direction).