[0296] In an alternate embodiment, surface features may also be used to enhance surface area for boiling. The size of the surface features either recessed or protruded from the wall may also be smaller than the hydraulic diameter of the microchannels. The smaller dimensionality may enable the formation of smaller bubbles than on a flat wall. In addition, flow advects within the surface features and as such there is a reasonable shear stress of the fluid against the wall surface. The shear stress within the surface features may be less than the shear stress on an analogous flat channel wall whose cross section intersects the top of the surface features. The magnitude of the shear stress in the surface feature may be 10% of the flat channel, and in some embodiments 50% or more of the comparable flat channel. The shear stress of fluid against the boiling wall in surface features is much higher than the shear stress found from other enhanced surface area structures as described in the literature because flow has minimal advection within the enhanced surface area regions as described in the literature.

EXAMPLE 11

Surface Roughness

[0297] Surface roughness and micropore structure within a microchannel has a dramatic effect on nucleate bubble formation. Surface roughness features generate perturbations in the flow field at the surface of the channel which in turn generate potential nucleation sites for bubble formation. Therefore, on a volumetric basis, there are more nucleation sites available in a microchannel application.

[0298] Surface roughness relative to the channel hydraulic diameter, ϵ/D_H, where ϵ is the average height of the surface roughness and D_H is the hydraulic diameter of the channel, is generally greater than that of conventional channels. Surface roughness can be measured by a profilometer, a stylus device used to trace across the surface profile. The results are expressed either as RA, which is the arithmetic average deviation from the center line of the surface, or as RMS, which is the root mean square of the deviations from the center line. RA or RMS values are given in either microns (same as micrometers or μm) or micro-inches (μ"). RMS will be approximately 11 percent higher than the RA number for a given surface. (RA×1.11=RMS). On most surfaces the total profile height of the surface roughness, or the peak-to-valley height will be approximately four times the RA value. A table of values for surface roughness in sanitary grade stainless steel pipes of all diameters is given below in Table 5.

TABLE 5

Surface Roughness Values for Sanitary Grade Stainless Steel Pipes

RMS (microinch)	RMS(μm)	RA (microinch)	RA (μm)	Grit Size
80	2.03	71	1.9	80
58	1.47	52	1.32	120
47	1.2	42	1.06	150
34	0.6	30	0.76	180
17	0.43	15	0.38	240
14	0.36	12	0.3	320

These values are the average data of many tests considered accurate to within ±5% from *Bulletin on Material Welds and Finishers* by DCI, Inc. (Meltzer 1993)

[0299] Based on the values given in Table 5, the maximum value for ϵ/D_H for a conventional system would be 2.03 micron/10 mm~2×10^{-4} m. However, based on experimentally determined surface features in microchannels (Wu and Cheng: 2003 and Honda and Wei: 2004) values for ϵ/DH can be at least one order of magnitude greater (~10^{-3} m).

[0300] Engineered features in the surface of a microchannel can also enhance nucleate boiling. Among the geometrical parameters, the pore diameter was found to be most influential on the bubble departure diameter. It has been demonstrated experimentally (Ramaswamy et al., 2002) that there are distinct boiling regimes for enhanced structures similar to that for plain surfaces. For low to intermediate wall superheat values (4-12° C.), boiling took place in the isolated bubble regime. As wall superheat increases, bubble coalescence can begin to take place. The net result of this phenomenon is to create larger vapor bubbles which in turn lead to lower inter-phase heat transfer and reduced overall performance of the system. The coalescence phenomenon, however, can be controlled to some extent by varying the pore pitch. A slotted surface can assist nucleation. Other patterned surfaces can also be useful, such as a grid of subchannels on a wall or walls of a coolant channel.

[0301] In general, the average bubble departure diameter decreases with a decrease in the pore size (for constant wall superheat).

[0302] There is a primary reason why these enhancement features for nucleate boiling prove more successful in microchannel rather than conventional-sized channels. In most cases, the flow in a microchannel is laminar and the boundary layer occupies the full extent of the channel gap. With these enhancement features employed, the nucleate boiling can be increased throughout the entire boundary layer and hence throughout the entire cross-section of the microchannel flow. However, in a conventional channel application, the boundary layer (laminar or turbulent) occupies only a small percentage of the overall flow volume. Thus, enhancement features of this type will have relatively little impact on their performance.

EXAMPLE 12

Flow Distribution

[0303] For microchannel systems that have open manifolds connecting plural cooling channels, the invention may include flow control mechanisms such as described in U.S. patent application Ser. No. 10/695,400, published as 2005/0087767 which is incorporated by reference as if reproduced in full below, and from which **FIGS. 34***a* and *b* have been copied.

[0304] Barriers with uniformly distributed obstacles aligned in parallel with the connecting channel matrix can change the pressure loss to enter a matrix of connecting channels through turning and sudden expansion losses for sub-cooled or saturated liquids. The barriers can include, but aren't limited to, orifice plates, screens, grids, ordered filter material, and gratings. To achieve different flows into a set of microchannels, barriers with different flow resistances can be placed into manifold to tailor the flow to the microchannels as needed, though it is important to seal the sections downstream of the barrier from each other to avoid cross-channel leakage.

[0305] Barriers with uniformly distributed obstacles (barriers can create orifices) aligned in the header can create a