[0068] Generally, LTAF occurred at lower heat flux (from 13.5 to 16.6 W/cm2) with higher average mass flux (from 14.6 to 12.7 g/m^2-s); CTF occurred at the medium heat flux (18.8 W/cm^2) and medium mass flux (11.9 g/cm^2-s), and LTVAF occurred at higher heat flux (22.6 W/cm^2) and lower mass flux (11.2 g/cm^2-s). Among the three unstable boiling modes, oscillation amplitudes in LTVAF were the largest with oscillations of pressures and mass flux nearly out of phase.

[0069] L/D_H Values

[0070] All microchannel experiments are conducted with a certain fixed geometry. For the purposes of summarizing heat transfer performance for these devices, the length-to-diameter ratio, typically the channel length divided by the hydraulic diameter, L/D_H, has been found to be a very useful metric. Much of the prior art in the literature does not explicitly report the length of the channels used in their experiments. Those that do are listed below.

[0071] Brutin et al. (2003): L/D_H=100 and 250 (see description above under "Stability of Flow").

[0072] Wu et al. (2004): L/D_H=161 (see description above under "Stability of Flow").

[0073] Lee et al. (2003): An integrated microchannel heat sink consisting of shallow, nearly rectangular microchannels was used to study the effects of the micrometer-sized channel shape on the evolving flow patterns and thermal performance of the microsystem. The device used channels with a equivalent diameter D_H=24 microns and a total length of 19 mm giving L/D_H=792. Local nucleation and isolated bubble formation was found to be negligible. The dominant flow pattern is an unsteady transition region connecting an upstream vapor zone to a downstream liquid zone with an average location depending on the input power.

[0074] Warrier et al. (2002): Both single-phase forced convection and subcooled and saturated nucleate boiling experiments were performed in small rectangular channels using FC-84 as test fluid. Test sections consisted of five parallel channels with each channel having the following dimensions: hydraulic diameter D_H=0.75 mm and length to diameter ratio=409.8. The experiments were performed with the channels oriented horizontally and uniform heat fluxes applied at the top and bottom surfaces. The parameters that were varied during the experiments included the mass flow rate, inlet liquid subcooling, and heat flux. New heat transfer correlations were generated for subcooled and saturated flow boiling heat transfer.

[0075] Pettersen (2004): Liquid CO2 evaporation in microtubes of diameter 0.8 mm and length 0.5 m (L/D_H=625). Heat transfer and pressure drop measurements were conducted at varying vapour fraction for temperatures in the range of 0 to 25° C., mass flux 190-570 kg/(m^2-s), and heat flux 5-20 kW/m^2. Heat transfer results show significant influence of dryout, particularly at high mass flux and high temperature. The flow observations reflect increasing entrainment at higher mass flux, and a dominance of annular flow (slug flow and thin film boiling).

[0076] Engineered Features to Enhance Boiling

[0077] Finally, boiling heat transfer characteristics of a microchannel can also be enhanced by applying a porous coating or in some means engineer porous or grooved structures on the wall surfaces of a microchannel. Ammerman and You (2001), for instance, described experimental work using porous coatings on a channel of width 2 mm and total length of 8 cm. The heat transfer characteristics for convective boiling using the coated channel and an uncoated channel with the same dimensions and flow mass fluxes were compared. The coated microchannel exhibited increase in heat transfer coefficient as well as a higher allowable critical heat flux.

[0078] Honda and Wei (2004) report work to enhance boiling heat transfer from electronic components immersed in dielectric liquids by use of surface microstructures. The microstructures developed include surface roughnesses produced by sandblast, sputtering of SiO_2 layer followed by wet etching of the surface, chemical vapor deposition of SiO_2 layer etc., a brush-like structure (dendritic heat sink), laser-drilled cavities, reentrant cavities, microfins, alumina particle spraying, painting of silver flakes or diamond particles, and heat sink studs with drilled holes, microfins and microchannels, pin fins etc. The primary focus of the study included the mitigation of incipience temperature overshoot, enhancement of nucleate boiling heat transfer, and increasing the critical heat flux. Their findings are as follows:

[0079] Complex microroughness, microreentrant cavity and microporous structure are effective in decreasing boiling incipience superheat. However, the microreentrant cavity tended to fill with liquid when the channel surface is subcooled. The mechanism of reduced boiling incipience superheat by the surface microstructure is not well understood.

[0080] Surface roughness is effective in enhancing nucleate boiling. However, the authors could not directly relate the surface roughness parameter E/DH to heat transfer enhancement. They found that surface roughness produced by the deposition of thin SiO_2 film (such as in microchip applications) is effective in increasing the critical heat flux.

[0081] Surface cavities are effective in enhancing nucleate boiling and increasing critical heat flux. In the range of surface cavity mouth diameter deq=1.6-9 microns, the cavity with larger deq was observed to be more effective in generating bubble nucleation sites.

[0082] Microporous structures are most effective in enhancing nucleate boiling. However, the slope of boiling curve of the microporous surface decreases sharply in the high-heat-flux region and the wall superheat at the CHF point is higher than the maximum allowable temperature for certain microchip applications.

[0083] the authors discovered that micropin-fins are most effective in increasing the critical heat flux, q_{CHF}. The boiling curve of micropin-finned surface shows a sharp increase in q with increasing ΔT_{sat} (ΔT_{sat}=wall superheat=$T_{wall-Tsat}$). The q_{CHF} increases monotonically with increasing Δ_{sub} (ΔT_{sub}=liquid subcooling=$T_{sat}-T_{boil}$). The optimum fin spacing that gives the highest q_{CHF} decreases as ΔT_{sub} increases.

[0084] The surface microstructures act to hold growing bubbles on the surface for a longer time than the smooth surface. This is considered to be an important factor for enhanced heat transfer obtained by the surface microstructures.