

Contents

1	Introduction.....	1
1.1	Overview: Moore's Law and IC Cooling.....	1
1.2	Electroosmotic Micro Coolers.....	7
1.2.1	Electroosmotic Pumps.....	8
1.2.2	Two-Phase Microchannel Heat Sinks.....	9
1.3	Scope of the Book.....	10
2	Two-phase Microchannel Heat Sinks: Problems and Challenges	13
2.1	Background: Forced Convective Internal Flow	13
2.1.1	Internal Flow in Macroscale Channels	13
2.1.2	Two-phase Flow in Microchannels	14
2.2	An Instrumented Microchannel Heat Sink	16
2.2.1	Instrumented Heat Sink Design.....	16
2.2.2	Device Fabrication	18
2.3	Experimental Results	20
2.3.1	Experimental System.....	20
2.3.2	Thermometer Calibration.....	22
2.3.3	Single-phase Forced Convective Cooling.....	24
2.3.4	Two-phase Forced Convective Cooling.....	25
2.4	Problems and Challenges	30
3	A Thermal Experimental System with Freestanding Microchannels.....	33
3.1	Thermal Isolation of Microchannels—Design Concept	33
3.2	Heat Distribution—Thermal Resistance Model.....	35
3.3	Thermometry—Wall Temperature Measurement.....	38
3.3.1	Doped Silicon Resistor as Both Heater and Thermometers	38
3.3.2	Aluminum Heaters and Doped Silicon Thermometers	40
3.3.3	Doped Poly Silicon Heaters and Thermometers.....	42
3.3.4	Other Thermometry.....	43
3.4	Experimental and Data Acquisition Systems.....	45
3.4.1	Experimental System Configuration	45
3.4.2	Data Acquisition System Configuration	47
3.5	Fabrication of Instrumented Single-channel Devices.....	52

4 Measurements and Modeling of Two-phase Flow in Microchannels	55
4.1 Review of Previous Research.....	55
4.2 Design Parameters of Test Devices	56
4.3 Two-phase Flow Measurements	59
4.3.1 Measurement Error Analysis	59
4.3.2 Multi-channel Device Measurements.....	59
4.3.3 Single-channel Device Measurements.....	62
4.3.4 Flow Patterns	65
4.4 Modeling of Two-phase Internal Flow	66
4.4.1 Heat Loss Estimation	66
4.4.2 One-dimensional Finite Volume Model for Two-phase Internal Flow	68
4.5 Discussion	70
5 Boiling Regimes and Transient Signals Associated with the Phase Change	73
5.1 Background: Boiling Regimes in Large and Small Channels.....	73
5.1.1 Nucleate Boiling in Large, Horizontal Tubes	73
5.1.2 Boiling in Microchannels—Previous Research.....	73
5.2 Design Parameters of Test Devices	75
5.3 Visualization of Nucleate Boiling in Microchannels	77
5.3.1 Bubble Nucleation in Microchannels	78
5.3.2 Two-phase Flow Regimes in Microchannels	80
5.4 Transient Characteristics of the Two-phase Flow.....	84
5.4.1 Transient Pressure Fluctuations During the Phase Change.....	84
5.4.2 Pressure Drop During the Phase Change	91
5.4.3 Transient Wall Superheat During the Phase Change	93
5.5 Discussion	93
6 Enhanced Nucleate Boiling in Microchannels	95
6.1 Background: Bubble Nucleation in Microchannels	95
6.1.1 “Evaporating Space” Hypothesis	95
6.1.2 Heterogeneous Nucleation on a Solid Surface	96
6.2 Enhanced-wall Microchannel Test Devices	98
6.2.1 Nucleation Sites in Plain-wall Channels.....	98
6.2.2 Design Parameters of Test Devices	99
6.3 Phase Change in Silicon Channels with Plain Walls	102
6.3.1 Plasma Etch Induced Surface Roughness	102
6.3.2 Plasma Etched Silicon Channels with DI Water	103
6.3.3 Plasma Etched Silicon Channels with Surfactant.....	106
6.3.4 Boiling Regime Chart for Plain-wall Channels.....	108
6.4 Phase Change in Silicon Channels with Enhanced Walls	110
6.4.1 Nucleation on the Enhanced Surface.....	110
6.4.2 Wall Temperature Measurement During the Phase Change	111
6.4.3 Boiling Regime Chart for Enhanced-wall Channels.....	115
6.5 Discussion	116

7 Conclusions.....	119
7.1 Phase Change in Sub-150 μm Diameter Microchannels	119
7.1.1 Bubble Nucleation Mechanisms.....	119
7.1.2 Two-phase Flow Regimes in Microchannels	120
7.1.3 Transient Characteristics	121
7.1.4 Two-phase Heat Transfer Model for Sub-100 μm Channels	121
7.1.5 General Design Rules for Two-phase Microchannel Heat Sinks	122
7.2 A Sample Design of a Two-phase Microchannel Heat Sink	123
7.3 Future Studies.....	124
Appendix A: Process Flow Chart for Single-channel Devices with Combined Heater and Thermometers	127
Appendix B: Process Flow Chart for Single-channel Devices with Separate Heater and Thermometers.....	129
References	131
Index.....	139



<http://www.springer.com/978-3-540-40181-0>

Silicon Microchannel Heat Sinks

Theories and Phenomena

Zhang, L.; Goodson, K.E.; Kenny, Th.W.

2004, IX, 141 p. 96 illus., 4 illus. in color., Hardcover

ISBN: 978-3-540-40181-0