







TK 7870.25 .Y44 2002

Copyright © 2002 The American Society of Mechanical Engineers Three Park Ave., New York, NY 10016

All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the publisher.

Statement from By-Laws: The Society shall not be responsible for statements or opinions advanced in papers . . . or printed in its publications (B7.1.3)

INFORMATION CONTAINED IN THIS WORK HAS BEEN OBTAINED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS FROM SOURCES BELIEVED TO BE RELIABLE. HOWEVER, NEITHER ASME NOR ITS AUTHORS OR EDITORS GUARANTEE THE ACCURACY OR COMPLETENESS OF ANY INFORMATION PUBLISHED IN THIS WORK. NEITHER ASME NOR ITS AUTHORS AND EDITORS SHALL BE RESPONSIBLE FOR ANY ERRORS, OMISSIONS, OR DAMAGES ARISING OUT OF THE USE OF THIS INFORMATION. THE WORK IS PUBLISHED WITH THE UNDERSTANDING THAT ASME AND ITS AUTHORS AND EDITORS ARE SUPPLYING INFORMATION BUT ARE NOT ATTEMPTING TO RENDER ENGINEERING OR OTHER PROFESSIONAL SERVICES. IF SUCH ENGINEERING OR PROFESSIONAL SERVICES ARE REQUIRED, THE ASSISTANCE OF AN APPROPRIATE PROFESSIONAL SHOULD BE SOUGHT.

For authorization to photocopy material for internal or personal use under circumstances not falling within the fair use provisions of the Copyright Act, contact the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923, Tel: 978-750-8400, www.copyright.com.

Library of Congress Cataloging-in-Publication Data

Yeh, L.-T. (Lian-Tuu), 1944-

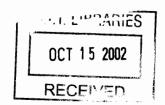
Thermal management of microelectronic equipment: heat transfer theory, analysis methods, and design practices / L.-T. Yeh and R. C. Chu.

p. cm

ISBN 0-7918-0168-3

1. Electronic apparatus and appliances – Cooling. 2. Electronic apparatus and appliances – Thermal properties. 3. Heat – Transmission. I. Chu, R. C. (Richard C.), 1933. II. Title.

TK7870.25.Y44 2002 621.381'04 - dc21



2001034086



TABLE OF CONTENTS

List of Figures List of Tables Nomenclature Foreword Preface		xi xvii xix xxiii xxv
Chap	ter 1 Introduction	1
1.1	Need for Thermal Control	1
1.2	Reliability and Temperature	3
1.3	Levels of Thermal Resistance	4
1.4	Thermal Design Considerations	5
1.5	Optimization and Life-Cycle Cost	6
Chap	ter 2 Conduction	9
2.1	Fundamental Law of Heat Conduction	9
2.2	General Differential Equations for Conduction	10
2.3	One-Dimensional Heat Conduction	16
2.4	Thermal/Electrical Analogy	17
2.5	Lumped-System Transient Analysis	20
2.6	Heat Conduction with Phase Change	25



vi • Table of Contents

Chap	ter 3 Convection	31
3.1	Flow and Temperature Fields	31
3.2	Heat Transfer Coefficient	34
3.3	Parameter Effects on Heat Transfer	35
3.4	Pressure Drop and Friction Factor	43
3.5	Thermal Properties of Fluids	46
3.6	Correlations for Heat Transfer and Friction	47
СНАР	TER 4 RADIATION	53
4.1	Stefan-Boltzmann Law	53
4.2	Kirchhoff's Law and Emissivity	
4.3	Radiation Between Black Isothermal Surfaces	
4.4	Radiation Between Gray Isothermal Surfaces	58
4.5	Extreme Climatic Conditions	
Chap	ter 5 Pool Boiling	67
5.1	Boiling Curve	67
5.2	Nucleate Boiling	
5.3	Incipient Boiling at Heating Surfaces	72
5.4	Nucleate Boiling Correlations	
5.5	Critical Heat Flux Correlations	77
5.6	Minimum Heat Flux Correlations (Leidenforst Point)	79
5.7	Parameters Affecting Pool Boiling	81
5.8	Effect of Gravity on Pool Boiling	87
Chap	ter 6 Flow Boiling	95
6.1	Flow Patterns	95
6.2	Heat Transfer Mechanisms	95
6.3	Boiling Crisis	98
6.4	Heat Transfer Equations	
6.5	Thermal Enhancement	109
6.6	Pressure Drop	109



DOCKET

Explore Litigation Insights



Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time** alerts and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

