Infrared and Millimeter Waves

VOLUME 9

MILLIMETER COMPONENTS AND TECHNIQUES, Part I

Edited by
Kenneth J. Button

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NATIONAL MAGNET LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS

1983

ACADEMIC PRESS

A Subsidiary of Harcourt Brace Jovanovich, Publishers

New York London
Paris San Diego San Francisco São Paulo Sydney Tokyo Toronto

ACADEMIC PRESS, INC.
111 Fifth Avenue, New York, New York 10003

United Kingdom Edition published by
ACADEMIC PRESS, INC. (LONDON) LTD.
24/28 Oval Road, London NW1 7DX

Library of Congress Cataloging in Publication Data

Main entry under title:

Infrared and millimeter waves.

Includes bibliographies and indexes.
Contents: v. 1. Sources of radiation.--v. 2. Instrumentation.--[etc.]--v. 9. Millimeter components and techniques. Part 1.
1. Infra-red wave devices. 2. Millimeter wave devices. I. Button, Kenneth J.
TA1570.I52 621.36'2 79-6949
ISBN 0-12-147709-6 (v. 9)

PRINTED IN THE UNITED STATES OF AMERICA

83 84 85 86 9 8 7 6 5 4 3 2 1

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PREFACE

This is the first of a series of books that will adhere closely to the theme "Millimeter Components and Techniques." We have not emphasized millimeter waves as the strict theme of a book since Volume 4: "Millimeter Systems" published in 1981. We are correcting our neglect of this emerging technology by publishing three books in rapid succession. This first one of the subseries opens with a chapter on the general topic of "Millimeter-Wave Communications" by Dr. K. Miyauchi. Then we address one of the most important problems in millimeter-wave components: the transmission line. We shall have five or six chapters on this subject eventually, but we start, of course, with Professor Tatsuo Itoh and Dr. Juan Rivera on "Comparative Studies of Millimeter-Wave Transmission Lines," which includes some important examples of devices. Chapter 3 deals with the emerging science and technology of "Dielectric Waveguide Electrooptic Devices" by Dr. Marvin B. Klein. There will be more on transmission lines and resonators in Volume 10. In the meantime, we shall open up three more aspects of this theme, namely, "Millimeter-Wave Propagation and Remote Sensing of the Atmosphere" by Edward E. Altshuler, "Technology of Large Radio Telescopes for Millimeter and Submillimeter Wavelengths" by J. W. M. Baars, and, finally, two chapters on gyrotrons.

The next book, Volume 10: "Millimeter Components and Techniques, Part II," will continue with the development of this theme. We shall have a chapter, "Microwave Open Resonator Techniques," by Professor A. L. Cullen and a chapter, "Microwave Open Resonators in Gyrotrons," by Professors Cheng-he Xu and Le-zhu Zhou. Dr. C. W. Roberson and colleagues have given us "A Free-Electron Laser Driven by a Long-Pulse Induction Linac." We are sure that we shall include "Integrated-Circuit Antennas" by David B. Rutledge and colleagues and "Near-Millimeter Imaging with Integrated Planar Receptors" by Professor K. S. Yngvesson. Finally, as promised, we have tried to get extensive reviews of emerging component and transmission techniques, and we shall not go into production until we have "Properties and Capabilities of Millimeter-Wave IMPATT Devices" by R. K. Mains and G. I. Haddad. Concerning detectors, we have a chapter on "^{3}He Refrigerators and Bolometers for Infrared and Millimeter-Wave Observations" by Dr. G. Chanin and Dr. J. P. Torre.

In the next volumes we have hopes for the long-awaited chapter on ''Groove Guide for Short Millimetric Waveguide Systems'' by Professor Douglas Harris and Yat Man Choi, ''The Modified H Guide'' by Professor Frederick Tischer, ''Millimeter-Wave Hybrid Integrated Circuit Techniques'' by A. G. Cardiosmenos, and ''Photoconductive Detectors'' by D. K. Shivanandan. For additional emphasis on components, we expect ''Millimeter-Wave Integrated Circuits'' from Charles Seashore, ''InP and GaAs Devices at Millimeter Wavelengths'' by I. G. Eddison, ''Dielectric-Based Active and Passive Millimeter-Wave Components'' by N. Deo, and ''Integrated Fin-Line Components for Radar and Radiometer Applications'' by W. Menzel. The chapters in the planning stages are literally too numerous to mention here so we refer you to the Preface of Volume 10.

CONTENTS OF OTHER VOLUMES

Volume 4: Millimeter Systems

Volume 5: Coherent Sources and Applications, Part I

Volume 6: Systems and Components

Volume 7: Coherent Sources and Applications, Part II

Volume 8: Electromagnetic Waves in Matter, Part I

Volume 10: Millimeter Components and Techniques, Part II
(In Press)

CHAPTER 1

Millimeter-Wave Communications

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I. Introduction

The exploitation of new frequency regions has always led to technological advances in the history of radio communication. The millimeter-wave region is a new frontier; it borders on the microwave region, which has been developed in the past 30 years and is now widely applied in various fields in modern society.

Improvements in microwave technology have made advanced and inexpensive equipment available. The steadily increasing demand for communications has resulted in the installation of numerous microwave systems and

ISBN 0-12-147709-6

a critical shortage of frequencies. Millimeter waves are quite attractive because their information-carrying capabilities are far greater than those of microwaves.

Millimeter-wave technology, in comparison with that of microwaves, has disadvantages such as large rainfall attenuation, large circuit loss, low efficiency of receivers, and low transmitter output power. Recent intensive research has solved many problems associated with these disadvantages and made it possible to provide systems that feature good performance in the millimeter-wave region. We are now able to produce devices and components that satisfy the performance, reliability, and productibility requirements necessary to build practical millimeter-wave communication equipment up to 100 GHz.

In Section II of this chapter, we shall describe devices and components for millimeter-wave communication systems. Active devices for the generation, amplification, and detection of signals are of primary importance. Only electron tubes and point-contact diodes were available for these purposes in the past. We shall not describe the electron tubes because they have a relatively narrow area of application owing to the large size and high voltage of their power supply, although they are still quite useful for high-power amplifiers and oscillators. The point-contact diodes have had substantial problems in terms of electrical performance, long-term stability, and reproducibility. It recently became possible to build practical millimeter-wave communication equipment employing sophisticated solid-state devices such as IMPATT, Schottky-barrier, $p-n$ junction, and $p-i-n$ diodes.

The most remarkable breakthrough was the invention of impact-ionization avalanche and transit-time (IMPATT) diodes and the improvement of gallium arsenide diodes. The IMPATT diode utilizes the avalanche effect of a reversely biased $p-n$ junction and is capable of oscillation and amplification in a frequency range of up to several hundred gigahertz. Although some cognates and different versions of the IMPATT diode, such as the TRAPATT, LSA, BARITT, and TUNNETT, have been proposed, the IMPATT diode is virtually the only device for carrier generation with sufficient power in the millimeter-wave region. Today, we can safely attain an oscillation power of about 8.0 mW at 100 GHz.

Gallium arsenide is a III–V compound and has an electron mobility approximately six times greater than that of silicon. The dielectric constants of gallium arsenide and silicon being equal, gallium arsenide provides us with diodes whose cutoff frequency is six times higher than that of silicon diodes. As a result of the improvement of the impurity doping and surface treatment technology of semiconductors, we can now obtain good diodes whose cutoff frequency is higher than 1000 GHz and whose current slope factor is very close to the theoretical limit.