



经典电介质科学丛书

Classic Dielectric Science Book Series

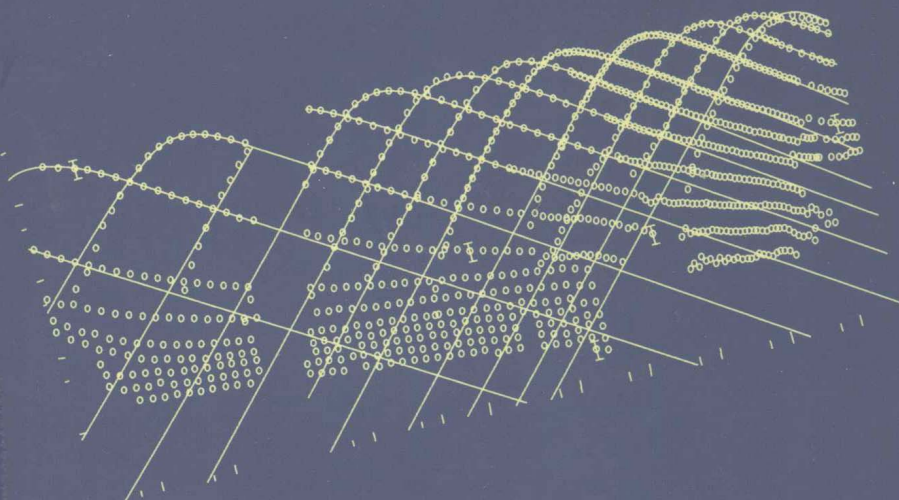
丛书主编 姚熹 (Yao Xi, Series Editor)

普适弛豫定律

Universal Relaxation Law

(影印版)

[英] A. K. 琼克 著
(A. K. Jonscher)



西安交通大学出版社
XI'AN JIAOTONG UNIVERSITY PRESS



经典电介质科学丛书

Classic Dielectric Science Book Series

丛书主编 姚熹 (Yao Xi, Series Editor)

普适弛豫定律

Universal Relaxation Law

(影印版)

[英] A. K. 琼克 著
(A. K. Jonscher)

Founder of Chelsea Dielectrics Group

1990 Whitehead Memorial Lecturer



西安交通大学出版社

Xi'an Jiaotong University Press

内容提要

本书是作者所著《固体中的介电弛豫》一书的姊妹篇,其内容是前作的延续和深化,被电介质领域的许多研究者奉为经典。作者在对普适介电弛豫进行系统描述的基础上,将其概念外推到其他传统电介质研究不涉及的弛豫过程中。书中介绍了“普适性”的含义、“平坦”的介电响应和低频介电弥散现象,讨论了半导体中的介电响应,以及发光、化学反应和力学弛豫等非介电过程的弛豫现象,并从理论角度对上述实验现象进行了解释。

本书可作为物理、电子、材料、电气等相关专业的教师、研究生和科研人员的参考书。

Copyright © 1996 by Chelsea Dielectrics Press.

This reprint of *Universal Relaxation Law*, originally published in English in 1996, is published by arrangement with Chelsea Dielectrics Press.

All rights reserved. This reprint published under license.

陕西省版权局著作权合同登记号:25-2007-046

图书在版编目(CIP)数据

普适弛豫定律=Universal Relaxation Law:英文/(英)琼克(Jonscher, A. K.)著.影印本.—西安:西安交通大学出版社,2008.2

(经典电介质科学丛书/姚熹主编)

ISBN 978-7-5605-2707-9

I.普... II.琼... III.介电弛豫-英文 IV.O482.4

中国版本图书馆 CIP 数据核字(2008)第 011180 号

书 名	普适弛豫定律 (Universal Relaxation Law)
著 者	[英]A. K. 琼克(A. K. Jonscher)
策划编辑	赵丽平 贺峰涛
责任编辑	贺峰涛 魏晓勇

出版发行	西安交通大学出版社 (西安市兴庆南路 10 号 邮政编码 710049)
网 址	http://www.xjtupress.com
电 话	(029)82668357 82667874(发行中心) (029)82668315 82669096(总编办)
传 真	(029)82669097
印 刷	西安交通大学印刷厂

开 本	687mm×1 012mm	1/16	印 张	27.375	字 数	438 千字
版 次	2008 年 2 月第 1 版		2008 年 2 月第 1 次印刷			
书 号	ISBN 978-7-5605-2707-9/O·274					
定 价	55.00 元					

读者购书、书店添货如发现印装质量问题,请与本社发行中心联系、调换。

订购热线:(029)82665248 (029)82665249

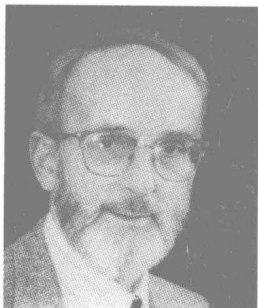
投稿热线:(029)82665380

读者信箱:banquan1809@126.com

版权所有 侵权必究

作者简介

ABOUT THE AUTHOR



A. K. 琼克, (A. K. Jonscher, 1922 - 2005), 生于波兰华沙, 1949 年在伦敦大学玛丽皇后学院以一级荣誉学士学位毕业, 并在该校 Harry Tropper 教授的指导下于 1952 年获得博士学位, 1951 年起在 GEC 研究实验室工作, 从事半导体器件物理原理方面的研究工作, 1962 年以 Reader 身份加入伦敦大学切尔西学院, 1965 年成为固态电子学教授, 1987 年成为伦敦大学皇家霍洛威与贝德福德斯学院荣誉教授, 1990 年受邀担任 IEEE“普适介电响应”杰出怀特海荣誉讲席。琼克教授在介电弛豫研究方面具有很深的造诣, 他于 1983 年和 1996 年分别出版的学术专著《固体中的介电弛豫》和《普适弛豫定律》, 在国际学术界享有盛誉。

A. K. Jonscher (1922 - 2005) was born in Warsaw, Poland. He received the B.Sc. degree in 1949 with 1st Class Honours in Electrical Engineering at Queen Mary College, University of London and obtained Ph.D. in 1952 under the late Professor Harry Tropper, leader of the wellknown Dielectrics Laboratory there. In 1951 he joined the staff of GEC Research Laboratories in Wembley, later named Hirst Research Centre, where he worked on physical principles of semiconductor devices. In 1960 appeared his monograph *Principles of Semiconductor Device Operation*. He joined Chelsea College, University of London, in 1962 as Reader and became Professor of Solid State Electronics in 1956. He became increasingly interested in the properties of dielectrics, with special emphasis on the “universality” of relaxation processes. In 1983 appeared his monograph *Dielectric Relaxation in Solids*. With the dissolution in 1987 of the Chelsea Dielectrics Group as a result of the recent reorganization of the University of London, he joined Royal Holloway and Bedford New College as Emeritus Professor and leader of a research group working on relation processes in a wide range of systems. In 1990 he was invited to give the prestigious Whitehead Memorial Lectureship of IEEE under the title “The Universal Dielectric Response”. In 1996 appeared his monograph *Universal Relaxation Law*. Professor Jonscher is the author of some 150 papers and has supervised fifty Ph.D. theses, and has a international reputation in his study of dielectric relaxation.

丛书主编简介

ABOUT THE SERIES EDITOR



姚熹, 1935 年生于中国江苏苏州。1957 年毕业于交通大学电机系, 1982 年获美国宾夕法尼亚州立大学固态科学博士学位。1957 年至今在西安交通大学任教, 1984 年起任西安交通大学教授。1989 年当选国际陶瓷科学院首批院士。1991 年当选中国科学院院士。2002 年当选美国陶瓷学会会士。2007 年因“在电子陶瓷科学 and 工程创新方面做出了杰出贡献”当选美国国家工程院外籍院士。

Yao Xi was born in Suzhou, Jiangsu, China, in 1935. He graduated from the department of electrical engineering, Jiaotong University in 1957, and received his Ph.D. of solid state science from the Pennsylvania State University in 1982. He has been a professor of Xi'an Jiaotong University since 1984. Dr. Yao was elected as an Academician in the first election of the World Academy of Ceramics in 1989. He was also elected as a Member of the Chinese Academy of Sciences in 1991 and a Fellow of the American Ceramic Society in 2002. In 2007, Prof. Yao was elected to be Foreign Associate of the National Academy of Engineering (USA) for his “contributions to the science and engineering innovations for electroceramics”.

Preface to the Classic Dielectric Science Book Series

Fifty years ago, I was sitting in a class at Jiaotong University in Shanghai, China taking a course called "DIELECTRIC PHYSICS" lectured by the late Professor Chen Jidan. I was one of the thirty students sitting in his class taking the course. This was the first time DIELECTRIC study was introduced to Chinese Universities. Since then, dielectric study became one of the major concerns of the science and technology community of China in developing its electrical and electronic engineering. Fifty years past, thousands of students, graduate students, professors, scientists and engineers have been engaged in the studies and applications of dielectrics in this country. In the past fifty years, the Xi'an Jiaotong University, Shanghai Jiaotong University, Electronic Science and Technological University, Shandong University, Zhongshan University, Sichuan University, Nanjing University, Tongji University and the Shanghai Institute of Ceramics, the Beijing Institute of Physics of the Chinese Academy of Sciences were heavily involved in dielectric studies and gave their various contributions to the development of dielectric study in China. Now, China is probably one of the most important countries in dielectric studies among the list of the ex Soviet Union and the United Kingdom. Late Professor Chen was the pioneer and founder of DIELECTRIC studies in China. The staidness, sureness and solemnness of his academic attitude are the invaluable treasure of the Chinese dielectric community. I would like to take the chance of writing this preface to pay my sincere respect to the late Professor Chen.

However, as a branch of solid state science, the advancement of dielectric science is not well satisfied as widely expected. Our basic understanding on the electro-physical process within real dielectrics beyond the classical electromagnetic theory is still rather poor. For example, the way how the charge assemblies respond to the external stimuli of electric field and the way of the communication and interaction among charge assemblies in real dielectrics are yet to be explored. Our understanding on local field, defects, inhomogeneous, space charges in real dielectric materials is to be profounded. As to the structure-property relationship of dielectric materials is still rather superficial. We are still struggling on how to calculate the dielectric constants of alkali-halogen crystals, water and other high dielectric constant materials. In contrast with other fields of solid state science such as metal, semiconductor and magnetics, dielectrics are probably the worst understood arena of solid state materials. The current status of dielectric science is not satisfied at all. Big efforts should be taken to catch up with the development of modern science and technology in this 21st century.

China is probably the country having the largest community of dielectric study in the world. Many of the old generation have devoted their career life focused on dielectrics in the past several decades. Next generation of dielectric study is now getting more mature and stronger. They have got better training and better working condition than their old generation. The Chinese dielectric community should be able to render more contribution to the advancement of dielectric science. However, dielectric science is now not yet in the main stream of solid state science. Many of the important publications were published twenty to sixty years ago in English. The first published book by P. Debye, *Polar Molecules*, was published in 1928. These important classics are not easily available to young scholars nowadays. To promote the dielectric studies in China, Electronic Materials Research Laboratory at Xi'an Jiaotong University proposed a publication project to introduce the most important classical publications on dielectrics from abroad and publish them in China, subjected to the consent of their original publishers. I am very pleased that the Xi'an Jiaotong University Press (XJTU Press) kindly agrees to support the publication project of Classical Dielectric Science Book Series (CDSBS). We

will carefully select the subjects and topics based on our best knowledge and judgment to keep the CDSBS including all the important and useful publications, while still keeping it concise. Needless to say, due to the restriction of our knowledge and information, there might be prepermissions in searching and collection. Any suggestion and recommendation from the reader of the series would be highly appreciated.

I would like to take the chance to thank the Chinese publisher, the Xi'an Jiaotong University Press, for their kind support of the project and their far sighted vision in promoting academic excellence, as well as the original publishers, such as the Oxford University Press and etc. for their generous consideration to permit the publication of their books in China. Highest esteem will be dedicated to the authors of the books. We may not be able to give our thanks to them individually. We gratitude them and hope them happy and healthy. I would also acknowledge Dr. Wei Xiaoyong and Dr. Xu Zhuo as well as the editors of the book series Ms Zhao Liping and Mr. He Fengtao for their enthusiastic and hard works to promote the CDSBS project being realized.

Yao Xi

Electronic Materials Research Laboratory,
Xi'an Jiaotong University
April 20, 2006

PREFACE

Felix qui potuit rerum cognoscere causas *
Virgil

There has been a good deal of progress in the twelve years since the Publication of Dielectric Relaxation in Solids, referred to in the following as DRS, which presented the first outline of the Author's concept of the "universal" dielectric relaxation law. The experimental foundation was by then sufficiently well established to enable a convincing picture to be formed of the "true" behaviour of dielectric materials, as distinct from the idealised responses which were required by this or other pet theory developed in the past eighty years, or so. Above all, we were able to show that the "universality" went much further than would have been expected on the basis of the various particular theoretical treatments developed for this or that kind of material. This may be said to have been an important realisation, but the missing element at that time was an adequate theory of this universal response – and even though a simplified treatment of the then new many-body theory by Dissado and Hill was given in Chapter 8 of DRS, this had become superseded soon after the book's publication by a more advanced version which we are attempting to summarise in Chapter 11 of the present Monograph.

The essential point which appears to be true is that DRS was at that time the first - and arguably remains to this day the only - textbook taking the concept of "universality" as its starting point. This is important, because only within this framework is it possible to construct a coherent picture of the totality of dielectric relaxation processes, and only with this picture in mind it is possible to attempt the formulation of a comprehensive theoretical understanding.

It is highly relevant that although DRS appears to have been well received by its readers and has sold a very satisfying number of

* Happy is he to whom it was given to understand the causes of things.

copies, its treatment by reviewers at the time of publication showed a virtually complete lack of understanding of its message. Some reviews were completely bland and non-committal, others were somewhat caustic, but none seemed to take up the principal message of universality, be it with approval or with condemnation. The conclusion must be that the reviewers were not prepared to accept the message of universality and that the readers themselves had to become gradually attuned and used to it.

The great advance of the past twelve years since the publication of DRS lies in the wide recognition of the general applicability of this approach, while the validity of the principal earlier theory based on distributions of relaxation times is equally widely discounted among theoretical workers. Once the principle of universality had become accepted, the way was paved for a more concerted theoretical effort aimed at an understanding the universal law of relaxation. Even so, the publication of the present Monograph was deliberately delayed by at least four years while awaiting the clarification of the theoretical position. Thus, we now have several alternative approaches to the theory of relaxation and although at the time of going to press there is as yet no firm agreement on which of these is the most likely to be true, there is at least a solid foundation on which to build the final approach to understanding. We have now decided that the time is finally ripe for the publication of the present Monograph, despite the fact that there is, as yet, no firmly agreed theoretical picture.

Our own choice in respect of accepted theories lies with the stochastic treatment by Karina Weron and her colleagues, presented along with several others in Chapter 11, while leaving to the judgement of posterity our own preferred approach based on the "energy criterion", Chapter 12. The final resolution of the theory of the "universal" response remains one of the major challenges in theoretical Solid State Physics. This is especially so in view of the universality found in several other relaxation phenomena, such as semiconductors, luminescence, mechanical and chemical reaction kinetics, all of which are being treated in the present Volume.

I am profoundly grateful to several colleagues for their advice and help in the preparation of the present book. Among them should be mentioned Len Dissado, Robert Hill, Jeppe Dyre, Allen Hunt and Vivian Halpern for their help with theories, Friedrich Kremer whose results form the background to the jacket design, Gunnar

Niklasson for his help with fractal theories and for providing unpublished data presented in Chapter 4, Andrzej Plonka for his help with the presentation of chemical reaction kinetics, Uno Gäfvert for help with the treatment of field recovery. Professor Koizumi kindly supplied frequency domain numerical data for the KWW function, some of them unpublished. I am also grateful my recent Graduate Students Naquiba Bano, Najeeb Siddiqui, Birjees Nafis, Altaf Husain and Aishah Isnin, whose results appear in some cases ahead of publication. However, my greatest debt is to Karina Weron, who has spent a great deal of time and effort on the formulation and later revision of the relevant treatment in Chapter 11, especially the Appendix.

After the dissolution of the former Chelsea College where the first Monograph was written, I am grateful to the Authorities of Royal Holloway, University of London, for giving me hospitality during the five years since my retirement. The expert and patient help of Susan May in the preparation of copies of diagrams has contributed to the external appearance of this Monograph. Stuart Flockton's and Colin Winterton's intimate knowledge of the workings of Macintosh word processors bailed me out of innumerable difficulties when the beastly machine would not do what it was expected to do. I also appreciate the help given on numerous occasions by the staff of Wavemetrics, creators of the IGOR software for processing and graphical representation of data.

Andrew K Jonscher

Royal Holloway
University of London

November 1995

ACKNOWLEDGEMENTS

Figure 1.1 reproduced from A Hofmann, F Kremer, E W Fischer and A Schönhals in Disorder Effects on Relaxation Processes, Eds R Richert and A Blumen, p. 309, Figure 105, by kind permission of Springer Verlag GbmH KG.

Figure 1.15 reproduced with permission from A K Jonscher, J Chem Soc:Faraday Trans 2, 82, p 75, 1986, Figure 4.

Figures 2.5, 2.6, 2.8 reproduced from A K Jonscher and N M Robinson, Solid State Electronics, 31, p 1277 1988, Figures 7, 8, 11, with permission from Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington OX5 1GB.

Figure 2.7 reproduced from S S H Zaidi and A K Jonscher from Semiconductor Science & Techn, 2, 587, 1987, with permission from Institute of Physics Publications.

Figures 2.12, 2.13, 2.14 reproduced from A K Jonscher and T J McCarthy, Semiconductor Science & Techn, 1,150 1986, Figures 8, 9, 10, with permission from Institute of Physics Publications.

Figure 2.20 reproduced from A K Jonscher and N Siddiqui, Solid State Electronics, 34, 1201, 1986, Figure 3, by kind permission of Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington OX5 1GB.

Figure 2.22 reproduced from A K Jonscher, C Pickup and S S H Zaidi, Semiconductor Science & Techn 1, 71, 1986, by kind permission of Institute of Physics Publications.

Figures 3.2, 3.3, 3.6, 3.8, 3.14 reproduced from A K Jonscher and A de Polignac, J Phys C:Solid State Physics 17, 6493, 1984, Figures 19, 18, 5, 14, 17 by kind permission of Institute of Physics Publications.

Figure 3.4 reproduced from T Fujita, K Takiyama, F Nishiyama and M Nishi, phys stat solidi (b) 99, K97, 1980, by kind permission of Akademie Verlag GmbH.

Figure 3.7 reproduced from D G Thomas, J J Hopfield and K Colbow, Proc 7th Intern Conf on Physics of Semiconductors, p 67 1964, by kind permission of Dunod Cie.

Figure 3.9 reproduced from J T Randall and M H F Wilkins, Proc Roy Soc A184, 347 1945, by kind permission of The Royal Society.

Figure 3.11 reproduced from C J Delbecq, Y Toyozawa and P H Yuster, Phys Rev B 9, p 4497, 1974, Figure 1, by kind permission of American Institute of Physics.

Figure 3.12 reproduced with permission from S Kuboniwa, H Kawai and T Hoshina, Jap J Appl Phys 19, 1647, 1980, Figure 10.

Figure 3.13 reproduced with permission from J J Donoghue and K E Davis, J Electrochem Soc 115, 285, 1968, Fig 9.

Figure 3.17 reproduced from J R Li and A K Jonscher, Semiconductor Science and Techn 2, 233,1987, Fig 5 with permission from Institute of Physics Publications.

Figures 4.3, 4.4, 4.5 reproduced with permission from K Buckingham and W Reddish, Proc IEE 114, 1810, 1967, Figures 1, 2, 3

Figure 5.8 reproduced from A K Jonscher, C Pickup and S S H Zaidi, Semiconductor Science and Technology 1, 71, 1986, Fig 6a) with permission from Institute of Physics Publications.

Figure 5.9 reproduced with permission from M A Chaudhry and A K Jonscher, J Materials Science 20, 3581, 1985, Figure 7.

Figure 5.10 reproduced with permission from T Ramdeen, L A Dissado and R M Hill, *J Chem Soc, Faraday Trans 1*, 80, 325, 1984, Figure 3c).

Figure 5.11 reproduced with permission from M Shablahk, L A Dissado and R M Hill, *J Biological Physics* 12, 63, 1984, Figure 8.

Figures 5.13, 5.14, 5.15, 5.16 reproduced with permission from A R Haidar and A K Jonscher, *J Chem Soc:Faraday Trans 1*, 82, 1986, p. 3535, Figures 3, 4, 5, 6, 9, 10.

Figure 5.17 reproduced with permission from A K Jonscher and A R Haidar, *J Chem Soc:Faraday Trans 1*, 82, 1986, p. 3553, Figure 2.

Figures 5.20 and 5.21 reproduced from S S H Zaidi and A K Jonscher from *Semiconductor Science & Technol*, 2, 587, 1987, with permission from Institute of Physics Publications.

Figure 5.22 reproduced from J B Bates, J C Wang and Y T Chu, *Solid State Ionics* 18, 1045, 1986, with kind permission from Elsevier Science BV.

Figure 5.23 reproduced with permission from A K Jonscher and T Ramdeen, *IEEE Trans EI* 22, 35, 1987 Figures 2 and 3

Figures 5.25, 5.26, 5.27 reproduced with permission from E F Owede and A K Jonscher, 1988, 135, 1757, Figures 2, 3b), 13, 14.

Figures 5.28, 5.30, 5.31, 5.32, 5.33 reproduced with permission from A Husain and A K Jonscher, *Physica B*, in the press.

Figures 5.34 and 5.35 reproduced with permission from M K Anis and A K Jonscher, *J Materials Science* 28, 3626 1993, Figures 4a), 5a) and 7.

Figure 5.37 reproduced with permission from M A Chaudhry and A K Jonscher, *J Materials Science* 23, 208, 1988, Figure 4.

Figure 5.40 reproduced with permission from A K Jonscher and A Husain, *Physica B*, in the press.

Figure 5.42 reproduced with permission from A K Jonscher and L Levesque, *IEEE Trans EI* 23, 209, 1988, Figure 2.

Figures 5.43 and 5.44 reproduced with permission from A K Jonscher and Ayub Birjees, *J Materials Science* 28, 208, 1879, Figures 4 and 6.

Figure 5.46 reproduced from M G Broadhurst, C K Chiang, K J Wahlstrand, R M Hill and L A Dissado in *J Molecular Liquids* 36, 515, 1987, by kind permission of Elsevier Science.

Figures 5.48, 5.49 reproduced from S H Liu and T Kaplan, *Fractals in Physics*, S Pietronero and E Tosatti (Eds), p 383, 1986, Figures 3 and 4, by kind permission of Elsevier Science.

Figures 7.2, 7.3, 7.4, 7.5 from A Plonka, *Developments in Dispersive Kinetics*, in *Progress in Reaction Kinetics* 16, 157, 1991, Figures 3.13, 6.2, 6.4, 6.5, with kind permission from Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington OX5 1GB.

Figure 8.7 reproduced with permission from M A Careem and A K Jonscher, *J Chem Soc:Faraday Trans 2*, 82, 7, 1986, Figures 1 and 4.

Figure 9.1 reproduced with permission from D G Fesko and N W Tschoegl, *J Polymer Sci C* 35, 51, 1971.

Useful Physical Constants

magnitude of electronic charge	$e = 1.602 \times 10^{-19}$	C
speed of light in free space	$c = 2.998 \times 10^8$	ms^{-1}
permittivity of free space	$\epsilon_0 = 10^7/4\pi c^2$	
	$= 8.854 \times 10^{-12}$	Fm^{-1}
mass of electron	$m = 9.109 \times 10^{-31}$	kg
mass of hydrogen atom	$m_H = 1.673 \times 10^{-27}$	kg
Boltzmann's constant	$k = 1.381 \times 10^{-23}$	JK^{-1}
	$= 8.620 \times 10^{-5}$	eVK^{-1}
thermal energy at 300K	$kT = 0.0259 \approx 1/40$	eV
Avogadro's number	$L = 6.023 \times 10^{23}$	mol^{-1}
atomic excitation energy	$1 \text{ eV} = 2.305 \times 10^4 \text{ calorie mol}^{-1}$	
Debye unit of dipole moment	$1 \text{ D} = (3 \times 10^{29})^{-1}$	
	approximately equal to charges $\pm e$	
	at a distance of $2 \times 10^{-11} \text{ m} = 0.2 \text{ \AA}$	

Contents

Preface	xi
Acknowledgements	xv
Useful Physical Constants	xvii
Chapter 1	
THE MEANING OF UNIVERSALITY	
1.1 The last twelve years	1
1.2 Basic definitions	6
1.3 Empirical response functions	10
1.4 Calculation of total polarisation	22
1.5 The nature of universality	24
1.6 Negative capacitance	27
1.7 Recovery of field on open-circuit	30
<i>Basic equations:</i>	32
1.8 Energy loss in the time domain	34
1.9 Concluding comments	38
Appendix 1.1 Integration in Logarithmic Coordinates	40
Appendix 1.2 Values of n and $\cot(n\pi/2)$	42
References to chapter 1	44
Chapter 2	
DIELECTRIC RESPONSE OF SEMICONDUCTORS	
2.1 Delayed electronic transitions	45
2.2 A simple barrier model	50

2.3	Response of Schottky diodes	58
	<i>Adventitious barriers on semi-insulating material</i>	61
2.5	Response of p-n junctions	62
	<i>High-purity p-n junctions</i>	64
	<i>Junctions with deep levels</i>	66
	<i>Heavily doped Zener diodes</i>	67
	<i>Conclusions regarding space charge region responses</i>	69
2.5	Junction diffusion capacitance	72
	<i>a) Low-frequency response</i>	74
	<i>b) High-frequency response</i>	75
2.6	Volume trapping-detrapping	77
2.7	Hopping conduction	83
	<i>Electronic processes</i>	83
	<i>Semi-insulating GaAs</i>	86
	<i>Ionic Transport</i>	86
2.8	Concluding comments	88
	References to Chapter 2	89

Chapter 3

LUMINESCENCE AND PHOTOCONDUCTIVITY

3.1	The relevance of the subject	91
3.2	Idealised light emission rates	93
3.3	Analytical formulation	95
	<i>The limit of rapid trapping</i>	97
3.4	Review of luminescence data	100
	<i>Exponential decays</i>	101
	<i>Simple power law decays</i>	103
	<i>More complex behaviours</i>	109
3.5	Conclusions from luminescence	111
3.6	Photoconductivity in the F-D	112
	<i>Principles of photoconductive behaviour</i>	113
	<i>Analytical formulation</i>	116
3.7	Conclusions	119
	References to Chapter 3	121

Chapter 4

"FLAT" DIELECTRIC RESPONSE

4.1	Low-loss dielectrics	123
4.2	The concept of "flat" loss	125
4.3	Experimental evidence	127
4.5	"Trans-universal" response	134
4.6	General conclusions	141
References to Chapter 4		142

Chapter 5

LOW-FREQUENCY DISPERSION

5.1	Introduction	143
5.2	Types of LFD characteristics	145
	<i>Frequency-domain response</i>	145
	<i>Time domain response</i>	148
5.3	Experimental conditions	150
5.4	Volume LFD	152
	<i>TD response of zeolites</i>	160
5.5	Interfacial LFD	161
	<i>Fast ionic conductors</i>	165
5.6	Surface conduction	167
5.7	Granular media	177
5.8	Fibrous hydrophyllic materials	185
5.9	Biological samples	187
5.10	Proposed mechanisms of LFD	190
	<i>Interpretations of volume LFD</i>	190
	<i>Fractal interfaces</i>	191
	<i>Interpretation of Surface LFD</i>	194
5.11	The electrochemical mechanism	195
5.12	Alternating current conductivity	198
5.13	Delta-function response of LFD	200
5.14	LFD with hopping electrons	202
5.15	Concluding comments	205
References to Chapter 5		209