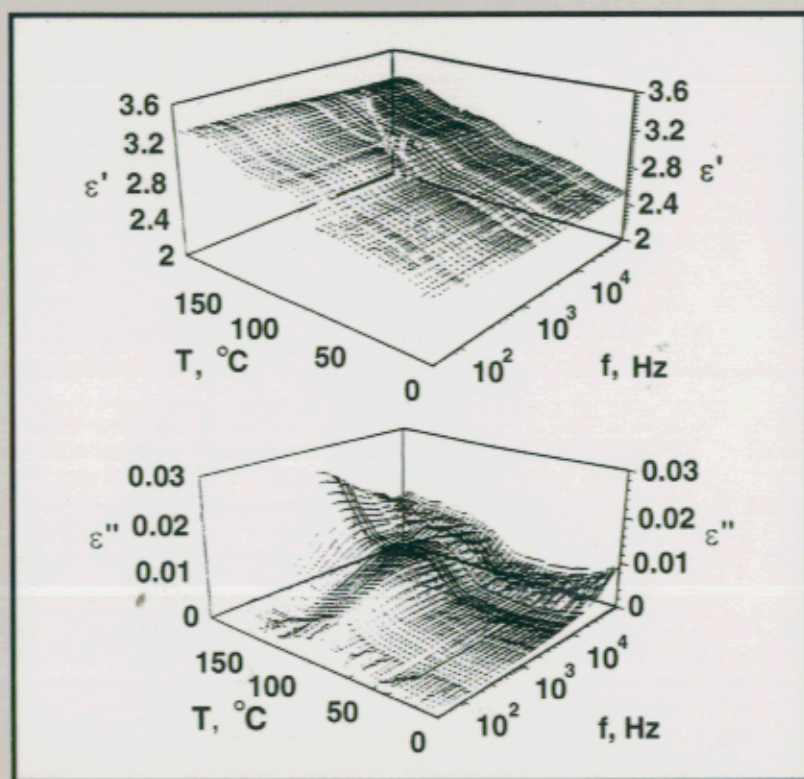


Dielectrics in Electric Fields



Gorur G. Raju

CONTENTS

Series Introduction	v
Preface	vii
Chapter 1	
Introductory Concepts	1
1.1 A dipole	1
1.2 The potential due to a dipole	2
1.3 Dipole moment of a spherical charge	5
1.4 Laplace's equation	7
1.4.1 A dielectric sphere immersed in a different medium	8
1.4.2 A rigid dipole in a cavity within a dielectric	12
1.4.3 Field in a dielectric due to a conducting inclusion	17
1.5 The tunneling phenomenon	18
1.6 Band theory of solids	20
1.6.1 Energy bands in solids	20
1.6.2 The Fermi level	21
1.6.3 Electron emission from a metal	25
1.6.4 Field intensification factor	28
1.7 Energy distribution function	29
1.8 The Boltzmann factor	30
1.9 A comparison of distribution functions	32
1.10 References	34

Chapter 2**Polarization and Static Dielectric Constant**

	35
2.1 Polarization and dielectric constant	35
2.2 Electronic polarization	37
2.3 The internal field	42
2.4 Orientational polarization	49
2.5 Debye equations	51
2.6 Experimental verification of Debye equation	58
2.7 Spontaneous polarization	61
2.8 Onsager's theory	63
2.9 Theory of Kirkwood	71
2.10 Dielectric constant of two media	77
2.10.1 Raleigh's formula	77
2.10.2 Wiener's formula	80
2.10.3 Formula of Lichtenecker and Rother	80
2.10.4 Goldschmidt's Equation	82
2.11 The dissipation factor	83
2.12 Dielectric constant of liquid mixtures	86
2.12.1 Raleigh's formula	86
2.12.2 Formula of Meredith and Tobias	88
2.12.3 Bruggeman's formula	88
2.12.4 Looyenga's formula	88
2.12.5 Böttcher's formula	88
2.13 Effect of high electric fields	90
2.14 Atomic polarizability	91
2.15 References	94

Chapter 3**Dielectric Loss and Relaxation-I**

	97
3.1 Complex permittivity	97
3.2 Polarization build up	100
3.3 Debye equations	104
3.4 Bi-stable model of a dipole	107
3.5 Complex plane diagram	110
3.6 Cole-Cole relaxation	113
3.7 Dielectric properties of water	117
3.8 Davidson-Cole equation	122
3.9 Macroscopic relaxation time	126
3.10 Molecular relaxation time	130
3.11 Straight line relationships	131

3.12	Frohlich's analysis	132
3.13	Fuoss-Kirkwood equation	135
3.14	Havriliak and Negami dispersion	138
3.15	Dielectric susceptibility	143
3.16	Distribution of relaxation times	147
3.17	Kramer-Kronig relations	155
3.18	Loss factor and conductivity	157
3.19	References	159
Chapter 4		
Dielectric Loss and Relaxation-II		161
4.1	Jonscher's universal law	161
4.2	Cluster approach of Dissado-Hill	168
4.3	Equivalent circuits	170
4.3.1	A series equivalent circuit	170
4.3.2	Parallel equivalent circuit	171
4.3.3	Series-parallel circuit	173
4.3.4	Summary of simple equivalent circuits	175
4.4	Interfacial polarization	178
4.5	The Absorption phenomenon	186
4.6	Frequency dependence of ϵ^*	193
4.7	References	195
Chapter 5		
Experimental Data (Frequency Domain)		197
5.1	Introduction to polymer science	202
5.1.1	Classification of polymers	202
5.1.2	<i>Molecular weight and size</i>	205
5.1.3	Glass transition temperature	207
5.1.4	Crystallinity of polymers	208
5.1.5	Thermally stable groups	212
5.1.6	Polymer degradation and defects	212
5.1.7	Dipole moment of polymers	214
5.1.8	Molecular structure	217
5.2	Nomenclature of Relaxation Processes	217
5.3	Non-Polar Polymers	220
5.3.1	Polyethylene	220
5.3.2	Poly(tetrafluoroethylene)	224
5.4	Polar Polymers	226

5.4.1	Polypropylene	227
5.4.2	Poly(vinyl chloride)	229
5.4.3	Polychlorotrifluoroethylene	235
5.4.4	Polycarbonate	239
5.4.5	Poly(methyl methacrylate)	243
5.4.6	Poly(vinyl acetate)	248
5.4.7	Polystyrene	251
5.4.8	Poly(ethylene terephthalate)	254
5.4.9	Polyisoprene	257
5.4.10	Epoxy Resins	260
5.4.11	Polyamides	261
5.4.12	Polyimides	264
5.5	Scaling methods	267
5.6	Concluding Remarks	269
5.7	References	277
Chapter 6		
Absorption and Desorption Currents		281
6.1	Absorption current in a dielectric	282
6.2	Hamon's approximation	289
6.3	Distribution of relaxation time and dielectric function	290
6.3.1	Cole–Cole function	290
6.3.2	Davidson–Cole function	290
6.3.3	Fuoss–Kirkwood function	290
6.3.4	Havriliak–Negami function	291
6.4	The Williams–Watts function	294
6.5	The $G(\tau)$ function for William-Watt curent decay	300
6.6	Experimental measurements	304
6.6.1	Poly(vinyl acetate)	306
6.7	Commercial dielectrics	310
6.7.1	Aramid paper	312
6.7.2	Composite polyamide	317
6.7.3	Poly(ethylene terephthalate)	319
6.7.4	Fluoropolymer	320
6.7.5	Polyimide	324
6.8	References	326
Chapter 7		
Field Enhanced Conduction		329
7.1	Some general comments	329

7.2	Motion of charge carriers in dielectrics	331
7.3	Ionic conduction	337
7.4	Charge injection into dielectrics	342
	7.4.1 The tunneling phenomenon	342
	7.4.2 Schottky emission	344
	7.4.3 Hopping mechanism	345
	7.4.4 Poole-Frenkel Mechanism	345
	7.4.5 Space charge limited current (trap free)	353
	7.4.6 Space charge limited current (with traps)	357
7.5	Space charge phenomenon in non-uniform fields	360
7.6	Conduction in selected polymers	363
	7.6.1 Conduction in polyethylene	365
	7.6.2 Conduction in fluoropolymers	366
	7.6.3 Aromatic polyimide	371
	7.6.4 Aromatic polyamide	374
7.7	Numerical computation	376
7.8	Closing remarks	379
7.9	References	380

Chapter 8

Fundamental Aspects of Gaseous Breakdown-I

		383
8.1	Collision phenomena	383
	8.1.1 Elastic collision	383
	8.1.2 Collision cross section	385
	8.1.3 Probability of collision	385
	8.1.4 Inelastic collisions	386
	8.1.5 Mean free path	387
	8.1.6 Ionization by collision	387
	8.1.7 Direct ionization	388
	8.1.8 Dissociative ionization	389
	8.1.9 Excitation	389
	8.1.10 Dissociative excitation	390
	8.1.11 Photoexcitation	390
	8.1.12 Electron attachment	390
	8.1.13 Electron detachment	391
	8.1.14 Recombination	392
	8.1.15 Secondary ionization coefficient	393
	8.1.16 Photo-ionization	394
	8.1.17 Electron swarm coefficients	395
8.2	Electron Growth in an Avalanche	402

8.3	Criteria for Breakdown	408
8.4	Paschen's Law	409
8.5	Breakdown time lags	412
	8.5.1 The statistical time lag	412
	8.5.2 Formative time lags in uniform fields	413
	8.5.3 Formative time lags in cylindrical geometry	416
8.6	The streamer mechanism	422
	8.6.1 The leader mechanism	424
8.7	Field distortion due to space charge	425
8.8	Sparkover characteristics of uniform field gaps in SF ₆	429
8.9	Sparkover characteristics of long gaps	431
8.10	Breakdown voltages in air with alternating voltages	433
8.11	Concluding remarks	434
8.12	References	436

Chapter 9

Fundamental Aspects of Electrical Breakdown—II **439**

9.1	Electron energy distribution functions (EEDF)	439
	9.1.1 EEDF: The Boltzmann equation	440
	9.1.2 EEDF: The Monte Carlo method	441
9.2	Streamer formation in uniform fields	446
9.3	The corona discharge	449
9.4	Basic mechanisms: Negative corona	450
9.5	Basic Mechanisms: Positive corona	453
9.6	Modeling of corona discharge: Continuity equations	455
9.7	Non-equilibrium considerations	460
9.8	Monte Carlo simulation: Negative corona in SF ₆	464
9.9	Monte Carlo Simulation: Positive corona in SF ₆	468
9.10	<i>Concluding Remarks</i>	472
9.11	References	473

Chapter 10

Thermally Stimulated Processes **475**

10.1	Traps in insulators	476
10.2	Current due to thermally stimulated depolarization (TSDC)	483
10.3	TSD currents for distribution of activation energy	487
10.4	TSD currents for universal relaxation mechanism	489
10.5	TSD currents with ionic space charge	490
10.6	TSD currents with electronic conduction	491
10.7	TSD currents with corona charging	492

10.8	Compensation temperature	494
10.9	Methods and analyses	498
10.10	TSD and AC dielectric properties	507
10.11	References	512

Chapter 11

Space Charge in Solids Dielectrics

515

11.1	The meaning of space charge	515
11.2	Polarons and traps	517
11.3	A conceptual approach	518
11.4	The thermal pulse method of Collins	522
11.5	DeReggi's analysis	526
11.6	Laser intensity modulation method (LIPP)	530
11.7	The pressure pulse method	532
11.7.1	Laser induced pressure pulse method	538
11.7.2	Thermoelastic stress waves	539
11.7.3	Pressure wave propagation (PWP) method	540
11.7.4	Nonstructured acoustic probe method	541
11.7.5	Laser generated acoustic pulse method	542
11.7.6	Acoustic pulse generated by mechanical excitation	543
11.7.7	Piezo-Electric Pressure Step Method (PPS)	543
11.7.8	Pulsed Electro-Acoustic Stress Method	544
11.7.9	Electron Beam Method	545
11.7.10	Special Techniques	546
11.8	Experimental Results	547
11.9	Closing Remarks	550
11.10	References	554

Appendix 1: Trade Names of Polymers 557

Appendix 2: General Classification of Polymer Dielectrics 559

Appendix 3: Selected Properties of Insulating Materials 561

Appendix 4: Relative Ranking of Thermoplastic Polymers 567

Appendix 5: Selected Properties of Polymer Insulating Materials 569

Index 571