1	Intr	oduction	1
	Refe	rences	7
2	Experimental techniques of luminescence		
	spe	ctroscopy	9
	2.1	Emission and excitation spectra	9
	2.2	Types of photodetectors	15
	2.3	Monochromators and spectrographs	31
		2.3.1 Dispersion and resolving power	33
		2.3.2 Throughput of monochromators and spectrographs	40
	2.4	Signal detection methods in luminescence spectroscopy	44
		2.4.1 Phase-synchronous detection	44
		2.4.2 Photon counting	48
	2.5	Signal-to-noise ratio in a scanning monochromator	53
	2.6	Fourier luminescence spectroscopy	57
	2.7	Spectral corrections	58
	2.8	Influence of slit opening on the shape of emission spectra	63
	2.9	Time-resolved luminescence measurements	67
		2.9.1 Direct imaging of the luminescence response	68
		2.9.2 Phase-shift method	70
		2.9.3 Time-correlated photon counting	72
		2.9.4 Boxcar integrator	73
		2.9.5 Streak camera	76
	2.10	Problems	78
	Refe	rences	80
3	Kin	etic description of luminescence processes	82
	3.1	Radiative and non-radiative recombination. Luminescence	
		quantum yield	82
	3.2	Monomolecular process	85
	3.3	Bimolecular process	87
	3.4	Stretched exponential	89
	3.5	Multiple processes present simultaneously	91
	3.6	Problems	96
	Refe	rences	96

4	Pho	nons and their participation in optical	
	phe	nomena	98
	4 1	Lattice vibrations—phonons	98
	4.2	Electron–phonon and exciton–phonon interactions	103
	4.3	Lattice vibrations associated with point defects	110
	4.4	A localized optical centre in a solid matrix—the	
		configurational coordinate model	112
	4.5	The shape of absorption and emission spectra of a localized centre	116
	4.6	Thermal quenching of luminescence	120
	4.7	Problems	121
	Refe	rences	122
_			
5	Cho	innels of radiative recombination in	
	sem	niconductors	123
	5.1	Overview of luminescence processes in crystalline semiconductors	123
	5.2	Recombination of free electron-hole pairs	124
		5.2.1 Direct bandgap	125
		5.2.2 Indirect bandgap	128
	5.3	Recombination of a free electron with a neutral acceptor $(e-A^{\circ})$ and	120
	5.4	of a free hole with a neutral donor $(h-D^{\circ})$	132
	5.4	Recombination of donor-acceptor pairs $(D^{-}-A^{-})$	130
	5.5	Luminescence from transition metal and rare earth ion impurities	144
	5.7	Problems	146
	Refe	rences	147
6	No	n-radiative recombination	148
	6.1	Transformation of the excitation energy into heat	149
		6.1.1 Multiphonon recombination	149
		6.1.2 Auger and bimolecular recombination	153
	6.2	Creation of lattice defects	157
	6.3	Photochemical changes	150
	0.4 Dofo	Problems	159
	Kele	Tences	100
7	Lun	ninescence of excitons	161
	7.1	Concept of the Wannier exciton	162
		7.1.1 Absorption spectrum of the Wannier exciton	165
		7.1.2 Direct bandgap: resonant luminescence of free	
		exciton-polaritons	168
		7.1.3 Direct bandgap: luminescence of free excitons with emission of	171
		7.1.4 Luminescence of free excitons in indirect-bandgap	1/1
		semiconductors	177
	72	Bound excitons	180

Co	nte	nts
----	-----	-----

		7.2.1 Excitons bound to shallow impurities	182
		7.2.2 Quantitative luminescence analysis of shallow impurities	
		in silicon	190
		7.2.3 Excitons bound to isoelectronic impurities	194
	72	7.2.4 Self-trapped excitons	199
	7.5 Dofor		201
	Kelei	lences	202
8	Hig	hly excited semiconductors	205
	8.1	Experimental considerations	206
	8.2	Excitonic molecule or biexciton	207
		8.2.1 Identification of the EM emission line	208
		8.2.2 Determination of biexciton parameters	216
	8.3	Collisions of free excitons	218
	8.4	Electron-hole liquid (EHL)	220
		8.4.1 Luminescence determination of EHL parameters	223
		8.4.2 Identification of the EHL emission band	226
		8.4.3 Coexistence of excitonic molecules with electron–hole	
	0.5	liquid	228
	8.5	Electron–hole plasma (EHP)	230
		8.5.1 Mott transition	230
	06	8.3.2 Luminescence of EHP	232
	0.0	Bose-Einstein condensation of excitons	234
		8.6.2 Luminescence experiment: Rose Einstein condensation	234
		ves or no?	236
	8.7	Problems	230
	Refe	rences	240
			210
9	Lum	ninescence of disordered semiconductors	242
	9.1	Densities of states in bands	242
	9.2	Temperature dependence of luminescence	244
	9.3	Distribution of luminescence lifetimes	248
	9.4	Spectral shape of the emission band	250
	9.5	Some other properties of luminescence of disordered	
		semiconductors	255
		9.5.1 Correlation effects	255
		9.5.2 Non-radiative recombination	256
		9.5.3 Luminescence of impurities and defects	258
	1.1	9.5.4 Luminescence 'fatigue'	260
	9.6	Problems	261
	Refe	rences	262
10	Stin	nulated emission	263
	10.1	Grant and the last of the last	200
	10.1	Spontaneous versus stimulated emission. Optical gain	263
	10.2	Optical gain in semiconductors	267

xi

10.	Spectral shape of the optical gain	271
10.	Stimulated emission in an indirect-bandgap	
	semiconductor	278
10.	Participation of excitons in stimulated emission	282
10.	Experimental techniques for measuring the optical	
	gain	287
	10.6.1 Variable stripe length (VSL) technique	287
	10.6.2 Pump and probe (P&P) method	295
10.	7 Problems	299
Re	erences	300
11.6	studiuminosconco	302
	erroluminescence	502
11	1 Historical notes	302
11	2 High-field electroluminescence	304
	11.2.1 Experimental considerations	304
	11.2.2 Mechanisms of high-field electroluminescence	308
	11.2.3 Intensity, spectral and temporal characteristics	316
11	3 Injection electroluminescence	321
	11.3.1 Electrical properties of a p-n junction	322
	11.3.2 Intensity, spectral and temporal characteristics of LEDs	327
11	4 Electroluminescence of a p-n junction biased in the reverse	
	direction	333
11	5 Problems	336
Re	ferences	337
125	atrania structure and luminosconce of	
	ectronic structure and furnitiescence of	220
lo	w-dimensional semiconductors	339
12	1 Basic types of low-dimensional semiconductors	340
	12.1.1 Semiconductor heterostructures	340
	12.1.2 Basic types of quantum-well heterostructures	342
12	2 Density of states in low-dimensional semiconductors	344
12	.3 Quantum wells (layers)—two-dimensional semiconductors	347
	12.3.1 Single quantum well with infinite barriers	347
	12.3.2 Quantum well with finite barriers	351
	12.3.3 Excitons in a quantum well	353
	12.3.4 Optical transitions in a quantum well	355
	12.3.5 Luminescence of quantum wells	357
12	.4 Quantum wires	359
12	.5 Quantum dots—nanocrystals	363
	12.5.1 Quantum dot with spherically symmetric potential	363
	12.5.2 Types of quantum dots according to the strength of the quantum	0.00
	confinement effect	365
	12.5.3 Luminescence of quantum dots	368
1	.6 Exciton-phonon interaction. Phonon bottleneck	371
1	.7 Some special phenomena	374
1	2.8 Problems	378
R	eferences	379

stru	ctures	
13.1	Excitonic molecule (biexciton) in a quantum well	
13.2	Trions in a quantum well	
13.3	Collisions of free excitons in a quantum well	
13.4	Electron-hole plasma (EHP) and electron-hole liquid (EHL) in	
	2D structures	
13.5	Biexcitons, EHP, and EHL in quantum wires	
13.6	Effects of high excitation in quantum dots (nanocrystals)	
13.7	Problems	
Refe	rences	

	14.1	Stimulated emission in quantum wells	400
		14.1.1 Localized excitons	401
		14.1.2 Radiative decay of an exciton with emission of an	
		LO-phonon (X–LO)	404
		14.1.3 Stimulated emission in electron-hole plasma (EHP)	405
	14.2	Stimulated emission in quantum wires	408
	14.3	Stimulated emission in nanocrystals	410
		14.3.1 Nanocrystals dispersed in a matrix	410
		14.3.2 Heterostructures with ordered quantum dots	416
	14.4	Random lasing	418
	14.5	Problems	420
	References		421
5	Silic	on nanophotonics	423
	15 1	Silicon noncomutale	120
	15.1	Silicon nanocrystals	424
	15.2	Optical gain in silicon nanocrystals	426
	15.3	Active planar waveguides made of silicon nanocrystals	428
	15.4	Electroluminescence of silicon nanocrystals	431
	15.5	Silicon nanocrystals combined with Er^{3+} ions	434
	15.6	Biological applications of silicon nanocrystals	437
	15.7	Problems	438
	Refer	rences	439

1

16	Photonic structures		441
	16.1	Photonic crystals	441
		16.1.1 Spontaneous emission	443
		16.1.2 Stimulated emission	446
	16.2	Microresonators	447
	16.3	Microcavities	449
	16.4	Single photon sources	451

16.5	Problems	453
Refe	erences	454
17 Spe	ectroscopy of single semiconductor	
nar	nocrystals	455
17.1	Basic principles	456
17.2	Experimental techniques	457
	17.2.1 Wide-field micro-spectroscopy	458
	17.2.2 Scanning techniques	460
17.3	Preparation of samples	465
	17.3.1 Electron- and ion-beam lithography	465
	17.3.2 Colloidal dispersions	466
17.4	Experimental observation of luminescence from individual	1.67
	nanocrystals	467
	17.4.1 Hidden fine structure of luminescence spectra	407
	17.4.2 Changes in spectra. Jumps, sints, binking	409
	17.4.4 Luminescence polarization	472
	17.4.5 Luminescence intermittency—blinking	478
17.5	Nanocrystals as sources of non-classical photon flux	485
	17.5.1 Measuring photon statistics	485
	17.5.2 Experimental manifestation of non-classical light emitted by a	
	single nanocrystal	487
17.6	Problems	490
Refe	erences	491
Annor	adicas	102
Apper	laces	493
А	Convolution	493
В	Emission spectrum of free excitons including phonon broadening	495
С	Luminescence of an excitonic molecule	497
D	Kinetic model of exciton condensation	502
E	Bose–Einstein condensation	503
F	Emission band due to strong electron–phonon interaction	505
G	Fitting the optical gain spectral shape in the model of \mathbf{k} -relaxation	507
Н	Reabsorption of luminescence in semiconductors	511
I	Oscillator strength	513
J	Fitting with a double exponential (Kocka's summation)	514
K	Absolute quantum yield of luminescent materials	515
L	Basic description of statistics of light from classical and	521
М	non-classical sources	521
IVI	point	526
	point	520
Sub	ject index	530
Mat	terial index	538