

Optical cavities and quantum emitters Koks, C.

Citation

Koks, C. (2024, January 25). *Optical cavities and quantum emitters*. *Casimir PhD Series*. Retrieved from https://hdl.handle.net/1887/3715075

Version:	Publisher's Version
License:	<u>Licence agreement concerning inclusion of doctoral</u> <u>thesis in the Institutional Repository of the University</u> <u>of Leiden</u>
Downloaded from:	https://hdl.handle.net/1887/3715075

Note: To cite this publication please use the final published version (if applicable).

OPTICAL CAVITIES AND QUANTUM EMITTERS

OPTICAL CAVITIES AND QUANTUM EMITTERS

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Leiden, op gezag van rector magnificus prof. dr. ir. H. Bijl, volgens besluit van het college voor promoties te verdedigen op donderdag 25 januari 2024 klokke 10.00 uur

door

Corné Koks

geboren te Oosterhout in 1996

Promotores:	Prof. dr. M. P. van Exter Prof. dr. M. A. G. J. Orrit	
Promotiecommissie:	Dr. S. R. K. Rodríguez Dr. M. Wubs	AMOLF Technical University of Denmark
	Prof. dr E. R. Eliel Prof. dr. D. J. Kraft	
	Prof. dr. ir. S. J. van der Molen	

Copyright © 2023 by C. Koks

Casimir PhD Series, Delft-Leiden 2023-41

ISBN 978-90-8593-586-5

An electronic version of this dissertation is available at https://scholarlypublications.universiteitleiden.nl/.

Tomorrow, we will do beautiful things. -A. Gaudí

CONTENTS

1	Introduction	1
	1.1 Quantum communication and quantum measurements	1
	1.2 Quantum emitters in an optical resonator	1
	1.3 Open microcavities	3
	1.4 Single-photon emitters	3
	1.5 Outline of this thesis	4
2	Microcavity resonance condition, quality factor, and mode volume are deter-	
	mined by different penetration depths	7
	2.1 Introduction	7
	2.2 Optical penetration in DBRs	8
	2.3 Methods	12
	2.4 Results	13
	2.5 Discussion	17
	2.A Coupled-mode theory and shift of (anti-)nodes	18
	2.B Effect of incident medium on frequency penetration depth L_{τ}	19
	2.C Ratio L_{τ} and L_D	20
3	Observation of mode-mixing in the spatial eigenmodes of an optical microcav-	
	ity	23
	3.1 Introduction	23
	3.2 Results	24
	3.3 Conclusion	29
	3.A Roundtrip operator <i>M</i>	29
	3.B Dynamic operator <i>K</i> and coupled modes	32
	3.C Complex fitting mode mixing ratio	33
	3.D AFM data yield mirror profile and coupling parameter	34
	3.E Repeated measurements on other microcavities	37
4	Fine structure in Fabry-Perot microcavity spectra	41
	4.1 Introduction	41
	4.2 Paraxial scalar modes	43
	4.3 Roundtrip operator and perturbation theory	44
	4.4 Nonparaxial scalar corrections	50
	4.5 Vector correction & L-S coupling	54
	4.6 Bragg (vector) correction \mathcal{H}_{Bragg}	57
	4.7 Mirror-astigmatic corrections.	59
	4.8 Discussion & residual \mathcal{H}_{rest} .	62
	4.9 Summary & outlook. \ldots	63
	4.A Comparison with Zeppenfeld-Pinkse	65
	4.B Bragg correction in detail	66

	4.C 4.D	Operator algebra 67 Hyperfine splittings 71
5	Obs	ervation of microcavity fine structure 73
5	Obs 5.1 5.2 5.3 5.4 5.5 5.4 5.5 5.A 5.B	ervation of microcavity fine structure 73 Introduction 73 Labeling of cavity eigenmodes 75 Comparison with theoretical predictions 77 Astigmatic correction 76 Conclusion 78 Coupling matrix for astigmatic and aspheric corrections 80 Hyperfine splitting 81 bing microcavity resonance spectra with intracavity emitters 85
U	6.1	Introduction
	6.2	Setup
	6.3	Joined length-wavelength scan
	6.4	Penetration depths
	6.5	Transverse mode group structure
	6.6 6.7	Mode coupling
	0.7 6.8	Acknowledgments
	6.A	Third-order frequency dispersion of DBRs
7	Exp	loring polarization orientation and power-dependent dynamics of single-
7	Exp pho 7.1 7.2	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride 97 Introduction 97 Experimental setup 98
7	Exp pho 7.1 7.2 7.3	loring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride 97 Introduction 97 Experimental setup 98 Confocal scan of the emitters 100
7	Exp pho 7.1 7.2 7.3 7.4 7.5	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride 97 Introduction 97 Experimental setup 98 Confocal scan of the emitters 100 Dipole orientation 100 Blinking at two time scales 107
7	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride 97 Introduction 97 Experimental setup 98 Confocal scan of the emitters 100 Dipole orientation 100 Blinking at two time scales 102 Four-level system 104
7	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7	Introduction97Introduction97Experimental setup97Confocal scan of the emitters100Dipole orientation100Blinking at two time scales102Four-level system104Conclusion105
7	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride97Introduction
7	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.A	Ioring polarization orientation and power-dependent dynamics of single-ton emitters in hexagonal Boron Nitride97Introduction97Experimental setup98Confocal scan of the emitters100Dipole orientation100Blinking at two time scales102Four-level system104Conclusion105Acknowledgments107Rate equations107
7	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.A 7.B 7.C	Ioring polarization orientation and power-dependent dynamics of single-ton emitters in hexagonal Boron Nitride97Introduction
7 Re	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.A 7.B 7.C	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride97Introduction
7 Re Su	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.6 7.7 7.8 7.A 7.B 7.C eferen	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride97Introduction
7 Re Su Sa	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.A 7.B 7.C efereer umma	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride97Introduction
7 Re Su Sa Ac	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.7 7.8 7.A 7.B 7.C 2 feren umma umen cknov	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride97Introduction97Experimental setup98Confocal scan of the emitters100Dipole orientation100Blinking at two time scales102Four-level system104Conclusion105Acknowledgments107Transition rates of emitter A.108Measurements on emitter C.113nces113ary123vatting127vledgements131
7 Re Su Sa Ac	Exp pho 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.7 7.8 7.7 7.8 7.A 7.B 7.C eferen umm umen cknov	Ioring polarization orientation and power-dependent dynamics of single- ton emitters in hexagonal Boron Nitride97Introduction97Experimental setup98Confocal scan of the emitters100Dipole orientation100Blinking at two time scales102Four-level system104Conclusion105Acknowledgments107Transition rates of emitter A.108Measurements on emitter C.111nces113ary123vatting131Ilum Vitae133