



Universiteit
Leiden
The Netherlands

Quantum dots in microcavities: from single spins to engineered states of light

Steindl, P.

Citation

Steindl, P. (2023, July 5). *Quantum dots in microcavities: from single spins to engineered states of light*. *Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/3629753>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3629753>

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

Quantum dots in microcavities: From single spins to engineered quantum states of light

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 woensdag 5 juli 2023
klokke 16:15 uur

door

Petr Steindl

geboren te Brno, Tsjechië
in 1994

Promotor: Prof. dr. D. Bouwmeester

Co-promotor: Dr. W. Löffler

Promotiecommissie: Prof. dr. J. Finley (Technical University of Munich, Munich, Germany)

Prof. dr. P. Senellart-Mardon (Université Paris-Saclay, Paris, France)

Dr. S. Bhattacharyya

Dr. E.P.L. van Nieuwenburg

Prof. dr. J.M. van Ruitenbeek

Prof. dr. J. Aarts

Casimir PhD series, Delft-Leiden 2023-12

ISBN: 978-90-8593-560-5

An electronic version of this thesis can be found at <https://openaccess.leidenuniv.nl>

The research project described in this thesis was conducted at the Leiden Institute of Physics, Leiden University. The project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862035 (QLUSTER) and by the Netherlands Organisation for Scientific Research (NWO/OCW), as part of the Frontiers of Nanoscience program (NanoFront) and the Quantum Software Consortium (project number 024.003.037 / 3368).



Universiteit Leiden



Copyright © 2023 Petr Steindl

The cover designed by Alexander Kuric shows a single-photon emitting device used in this thesis - a semiconductor quantum dot embedded in a Fabry-Perot microcavity.

Schematics of optical setups use components adapted from the *ComponentLibrary* by Alexander Franzen, which is licensed under a CC BY-NC 3.0 Licence.

Contents

1	Introduction	1
1.1	Single photons	1
1.2	From single to entangled photons	2
1.3	The QD as a spin-photon interface	3
1.4	Resonant laser spectroscopy	3
1.5	Thesis outline	4
2	Cavity-QD device with an electron blocking layer	5
2.1	Cavity design	6
2.2	A QD in a micropillar cavity	8
2.2.1	Growth	8
2.2.2	Electrical tuning of QD state	8
2.3	Trion identification of QD spin-state configuration in the presence of an optical cavity	10
2.3.1	Resonant Stark spectroscopy under cross-polarization	10
2.3.2	Resonant spectroscopy in an in-plane magnetic field	11
2.3.3	Semi-classical model	12
2.4	Single-photon emission	13
3	Cross-polarization extinction enhancement and spin-orbit coupling of light for quantum-dot cavity-QED spectroscopy	15
3.1	Introduction	16
3.2	Scattering elimination	17
3.3	Vector-beam effects upon multiple reflections	18
3.4	Single emitter polarization extinction improvement	19
3.5	Conclusions	22
3.6	Appendix	23
3.6.1	Scattering elimination with various analyzers	23
3.6.2	Maximal polarization extinction upon multiple reflections	24
4	Resonant two-laser spin-state spectroscopy of a negatively charged quantum dot-microcavity system with a cold permanent magnet	25
4.1	Introduction	26
4.2	Permanent magnet assembly	26
4.3	Spin-state determination	28
4.4	Two-color resonant laser excitation	30
4.5	Conclusions	33
4.6	Appendix	35
4.6.1	Permanent magnet assembly simulations	35
4.6.2	Experimental setup and characterization	36
4.6.3	Single-laser resonance fluorescence	37

4.6.4	Rate-equation model of resonant two-color spectroscopy of a negatively charged exciton	39
4.6.4.1	Spin population rate equations	39
4.6.4.2	2D two-color resonant excitation model	40
4.6.4.3	Estimate of excitation and detection rates	41
4.6.4.4	Model rates estimation	41
4.6.4.5	Excitation-power dependent two-color resonant excitation	42
5	Single-photon addition and photon correlations	47
5.1	Introduction	48
5.2	Displaced Fock states from quantum interference	48
5.2.1	Influence of loss	50
5.3	Photon correlations	50
5.4	Effect of photon indistinguishability	52
5.5	Single-photon addition with quantum dot sources	53
5.6	Conclusions	55
5.7	Appendix	56
5.7.1	Derivation of $g_{\theta}^{(2)}(0)$	56
5.7.2	Photon correlations: single-photon-added coherent states vs displaced Fock states	57
6	Artificial coherent states of light by multi-photon interference in a single-photon stream	59
6.1	Introduction	60
6.2	Single-photon source	60
6.3	Photon correlations between source and delay loop	63
6.4	Building artificial coherent states	63
6.5	Conclusions	66
6.6	Appendix	68
6.6.1	The two-photon picture	68
6.6.1.1	Detection of VH correlations	68
6.6.1.2	Detection of HH correlations	69
6.6.1.3	Relation to source correlations	70
6.6.1.4	Loss in the delay loop	70
6.6.2	Simulation details	71
6.6.2.1	Quantum interference at waveplate WP2 in the delay loop	72
6.6.2.2	Delay loop: Round-trip loss and diffraction	73
6.6.3	Visibility measurement	74
6.6.4	How many photons do interfere?	75
6.6.5	Properties of the artificial coherent state	76
	Bibliography	78
	Summary	99
	Samenvatting	101
	Curriculum Vitae	103

List of publications	105
Acknowledgements	107

