



AFRL-AFOSR-VA-TR-2015-0246

Quantum Photonic in Hybrid Cavity Systems with Strong Matter-Light Couplings

Hui Deng
UNIVERSITY OF MICHIGAN

08/24/2015
Final Report

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Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB
Arlington, Virginia 22203
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REPORT DOCUMENTATION PAGE			<i>Form Approved</i> OMB No. 0704-0188		
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1. REPORT DATE (DD-MM-YYYY) 24-08-2015		2. REPORT TYPE Final Performance		3. DATES COVERED (From - To) 01-07-2012 to 30-06-2015	
4. TITLE AND SUBTITLE Quantum Photonic in Hybrid Cavity Systems with Strong Matter-Light Couplings			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER FA9550-12-1-0256		
			5c. PROGRAM ELEMENT NUMBER 61102F		
6. AUTHOR(S) Hui Deng			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) UNIVERSITY OF MICHIGAN 503 THOMPSON ST ANN ARBOR, MI 48109-1340 US			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AF Office of Scientific Research 875 N. Randolph St. Room 3112 Arlington, VA 22203			10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/AFOSR RTB		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT A DISTRIBUTION UNLIMITED: PB Public Release					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT A novel, designable microcavity structure was developed in the project for exploring new manybody physics and quantum-device applications of property-designed quantum liquids. Specifically the following was achieved: 1. Strong-coupling between quantum-well excitons and cavity photons was demonstrated in the designable microcavity structure for the first time, establishing a robust light-matter hybrid states with designable properties. [Ref 1, 6] 2. Confinement and coupling of microcavity polaritons were readily implemented by design of the photonic crystal in the new cavity structure, allowing flexible device design and integration of the polariton system. Zero-dimensional polariton systems were created by reducing the area of the photonic crystal, coupling between multiple zero-dimensional polariton systems was controlled by design of the boundaries of the photonic crystals, and quasi-1D polariton featuring band-structures was also demonstrated. [Ref. 1-2, 6] 3. Spin-selectivity of the polaritons was demonstrated in the new cavity structure, enabling single-mode polariton lasing without ground-state degeneracy. The unique magnetic field r					
15. SUBJECT TERMS Quantum Photonic					
16. SECURITY CLASSIFICATION OF:		17. LIMITATION OF ABSTRACT	18. NUMBER OF		
Standard Form 298 (Rev. 8/98) Prescribed by ANSI Std. Z39.18					

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a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	UU	PAGES	19a. NAME OF RESPONSIBLE PERSON Hui Deng <hr/> 19b. TELEPHONE NUMBER <i>(Include area code)</i> 734-763-7835
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**Quantum Photonic in Hybrid Cavity Systems with
Strong Matter-Light Couplings**

Report Period: 7/1/2012-6/30/2015

Principal Investigator: Professor Hui Deng

Institution: University of Michigan

Award number: FA9550-12-1-0256

REPORT DOCUMENT

In this project, a novel, designable microcavity structure was developed for exploring new manybody physics and quantum-device applications of property-designed quantum liquids. Specifically the following was achieved:

1. Strong-coupling between quantum-well excitons and cavity photons was demonstrated in the designable microcavity structure for the first time, establishing a robust light-matter hybrid states with designable properties. [Ref 1, 6]
2. Confinement and coupling of microcavity polaritons were readily implemented by design of the photonic crystal in the new cavity structure, allowing flexible device design and integration of the polariton system. Zero-dimensional polariton systems were created by reducing the area of the photonic crystal, coupling between multiple zero-dimensional polariton systems was controlled by design of the boundaries of the photonic crystals, and quasi-1D polariton featuring band-structures was also demonstrated. [Ref 1, 2, 6]
3. Spin-selectivity of the polaritons was demonstrated in the new cavity structure, enabling single-mode polariton lasing without ground-state degeneracy. The unique magnetic field response of polariton condensation in single linearly-polarized state was also studied. [Ref 1, 3, 6]
4. Energy-momentum dispersion engineering of high-quality vertical microcavities was demonstrated theoretically and numerically utilizing the unique symmetry properties of the photonic crystal mirror. The curvature of the dispersion, controlling the effective mass, group and phase velocities and the density of states of the modes, can be varied by orders of magnitude. Even flat-bottom or Mexican-hat shaped dispersions could be created. This opens the door to creating photonic and polariton systems where the light propagation and matter-light interactions can be controlled by design without introducing loss or decoherence to embedded active media. [Ref 4]
5. A polariton laser with full intensity stability at the Poisson noise limit, a defining feature of coherent light, was demonstrated with the new cavity. Strong nonlinear interactions within the condensate, critical for polariton-based nonlinear devices, was measured and was shown to be greater than the decay rate of the condensate at high condensate occupancy numbers. [Ref 5]

The project supported three Ph.D. students, including one graduated in 2015 with a dissertation submitted [Ref 6]. Main achievements in the dissertation include items 1-3 above.

Publications:

- [1] Zhang, B., Wang, Z., Brodbeck, S., Schneider, C., Kamp, M., Höfling, S. & Deng, H. “Zero-dimensional polariton laser in a subwavelength grating-based vertical microcavity.” *Light Sci Appl* 3, e135 (2014).
<http://www.nature.com/lsa/journal/v3/n1/full/lsa201416a.html>

- [2] Fischer, J., Brodbeck, S., Zhang, B., Wang, Z., Worschech, L., Deng, H., Kamp, M., Schneider, C. & Höfling, S. “Magneto-exciton-polariton condensation in a sub-wavelength high contrast grating based vertical microcavity.” *Applied Physics Letters* 104, 091117 (2014). <http://scitation.aip.org/content/aip/journal/apl/104/9/10.1063/1.4866776>
- [3] Zhang, B., Brodbeck, S., Wang, Z., Kamp, M., Schneider, C., Höfling, S. & Deng, H. “Coupling polariton quantum boxes in sub-wavelength grating microcavities.” *Applied Physics Letters* 106, 051104 (2015). <http://scitation.aip.org/content/aip/journal/apl/106/5/10.1063/1.4907606>
- [4] Wang, Z., Zhang, B. & Deng, H. “Dispersion Engineering for Vertical Microcavities Using Subwavelength Gratings.” *Phys. Rev. Lett.* 114, 073601 (2015). <http://link.aps.org/doi/10.1103/PhysRevLett.114.073601>
- [5] Kim, S., Zhang, B., Wang, Z., Schneider, C., Brodbeck, S., Hofling, S., Kamp, M. & Deng, H. “Coherence Properties of a Single-Mode Polariton Laser.” *Frontiers in Optics 2014 LW2I.2* (2014). <http://www.opticsinfobase.org/abstract.cfm?URI=LS-2014-LW2I.2>
- [6] Zhang, B. “Low Dimensional Polariton Systemes in Subwavelength-Grating Based Microcavities.” Doctoral thesis. (2015). <http://deepblue.lib.umich.edu/handle/2027.42/111358>

1.

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Final Report

Primary Contact E-mail

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dengh@umich.edu

Primary Contact Phone Number

Contact phone number if there is a problem with the report

734-763-7835

Organization / Institution name

University of Michigan

Grant/Contract Title

The full title of the funded effort.

A Scalable Cavity Architecture for Quantum Optoelectronic in the Strong-Coupling Regime

Grant/Contract Number

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0256

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

HUI DENG

Program Manager

The AFOSR Program Manager currently assigned to the award

JOHN W. LUGINSLAND

Reporting Period Start Date

07/01/2012

Reporting Period End Date

06/30/2015

Abstract

A novel, designable microcavity structure was developed in the project for exploring new manybody physics and quantum-device applications of property-designed quantum liquids. Specifically the following was achieved:

1. Strong-coupling between quantum-well excitons and cavity photons was demonstrated in the designable microcavity structure for the first time, establishing a robust light-matter hybrid states with designable properties. [Ref 1, 6]
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Archival Publications (published) during reporting period:

1. Zhang, B., Wang, Z., Brodbeck, S., Schneider, C., Kamp, M., Höfling, S. & Deng, H. "Zero-dimensional polariton laser in a subwavelength grating-based vertical microcavity." *Light Sci Appl* 3, e135 (2014). <http://www.nature.com/lsa/journal/v3/n1/full/lsa201416a.html>
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4. Wang, Z., Zhang, B. & Deng, H. "Dispersion Engineering for Vertical Microcavities Using Subwavelength Gratings." *Phys. Rev. Lett.* 114, 073601 (2015). <http://link.aps.org/doi/10.1103/PhysRevLett.114.073601>
5. Kim, S., Zhang, B., Wang, Z., Schneider, C., Brodbeck, S., Hofling, S., Kamp, M. & Deng, H. "Coherence Properties of a Single-Mode Polariton Laser." *Frontiers in Optics 2014 LW21.2* (2014). <http://www.opticsinfobase.org/abstract.cfm?URI=LS-2014-LW21.2>
6. Zhang, B. "Low Dimensional Polariton Systmes in Subwavelength-Grating Based Microcavities." Doctoral thesis. (2015). <http://deepblue.lib.umich.edu/handle/2027.42/111358>

Changes in research objectives (if any):

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Change in AFOSR Program Manager, if any:

Original program manager: Dr. Howard R. Schlossberg. Current program manager: Dr. John W. Luginsland.

Extensions granted or milestones slipped, if any:

NA

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, \$K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

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Appendix Documents

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