



---

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

**Hui Deng**  
**UNIVERSITY OF MICHIGAN**

---

**08/24/2015**  
**Final Report**

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory  
AF Office Of Scientific Research (AFOSR)/ RTB  
Arlington, Virginia 22203  
Air Force Materiel Command

<b>REPORT DOCUMENTATION PAGE</b>			<i>Form Approved</i> OMB No. 0704-0188		
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services, Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.</b></p>					
<b>1. REPORT DATE (DD-MM-YYYY)</b> 24-08-2015		<b>2. REPORT TYPE</b> Final Performance		<b>3. DATES COVERED (From - To)</b> 01-07-2012 to 30-06-2015	
<b>4. TITLE AND SUBTITLE</b> Quantum Photonic in Hybrid Cavity Systems with Strong Matter-Light Couplings			<b>5a. CONTRACT NUMBER</b>		
			<b>5b. GRANT NUMBER</b> FA9550-12-1-0256		
			<b>5c. PROGRAM ELEMENT NUMBER</b> 61102F		
<b>6. AUTHOR(S)</b> Hui Deng			<b>5d. PROJECT NUMBER</b>		
			<b>5e. TASK NUMBER</b>		
			<b>5f. WORK UNIT NUMBER</b>		
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> UNIVERSITY OF MICHIGAN 503 THOMPSON ST ANN ARBOR, MI 48109-1340 US			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>		
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> AF Office of Scientific Research 875 N. Randolph St. Room 3112 Arlington, VA 22203			<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> AFRL/AFOSR RTB		
			<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>		
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b> A DISTRIBUTION UNLIMITED: PB Public Release					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> 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					
<b>15. SUBJECT TERMS</b> Quantum Photonic					
<b>16. SECURITY CLASSIFICATION OF:</b>		<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF</b>	Standard Form 298 (Rev. 8/98) Prescribed by ANSI Std. Z39.18	

DISTRIBUTION A: Distribution approved for public release.

<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified	UU	<b>PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b> Hui Deng <hr/> <b>19b. TELEPHONE NUMBER</b> <i>(Include area code)</i> 734-763-7835
----------------------------------	------------------------------------	-------------------------------------	----	--------------	---

**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.

**1. Report Type**

Final Report

**Primary Contact E-mail**

Contact email if there is a problem with the report.

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]
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.

### **Distribution Statement**

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

### **Explanation for Distribution Statement**

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

### **SF298 Form**

Please attach your SF298 form. A blank SF298 can be found [here](#). Please do not password protect or secure the PDF. The maximum file size for an SF298 is 50MB.

[formsf298-AFD-070820-035-filled-scanned.pdf](#)

**Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.**

[final-report-document.pdf](#)

**Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.**

### **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>
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 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):**

DISTRIBUTION A: Distribution approved for public release.



NA

**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**

**Report Document - Text Analysis**

**Report Document - Text Analysis**

**Appendix Documents**

**2. Thank You**

**E-mail user**

Aug 13, 2015 14:32:10 Success: Email Sent to: dengh@umich.edu