

## DOCTORAL THESIS

### Photon manipulation in plasmonic crystal

Chen, Shumei

*Date of Award:*  
2014

[Link to publication](#)

#### **General rights**

Copyright and intellectual property rights for the publications made accessible in HKBU Scholars are retained by the authors and/or other copyright owners. In addition to the restrictions prescribed by the Copyright Ordinance of Hong Kong, all users and readers must also observe the following terms of use:

- Users may download and print one copy of any publication from HKBU Scholars for the purpose of private study or research
- Users cannot further distribute the material or use it for any profit-making activity or commercial gain
- To share publications in HKBU Scholars with others, users are welcome to freely distribute the permanent URL assigned to the publication

# Abstract

Plasmonic devices, consisting of subwavelength nanostructures at optical frequency, have been widely applied to many research fields such as bio-sensing, super-resolution imaging, energy harvesting, nanolaser and so on. The strong confined electromagnetic fields in the affinity of nanostructures provides an efficient channel to guide, enhance, and modulate light energy beyond the diffraction limit. In this thesis, we first studied the plasmonic devices in linear optical regime, especially from the view of phase information in the light matter interaction; then more efforts were paid to the nonlinear plasmonics, in which the organic-plasmonic hybrid nanostructures provided a useful platform for demonstrating some interesting physical phenomena.

Firstly, we studied the fundamental optical properties of typically propagating surface plasmonic polariton (SPPs), which were generated by plasmonic gratings. Optical elliptical response of excited SPPs was studied experimentally and theoretically in both amplitude and phase domains. Then we studied the strong coupling effect from plasmonic Fabry-Perot nanocavity, in which giant Rabi splitting phenomenon with a splitting energy  $\sim 148$  meV was obtained experimentally. From these studies, the interaction of SPP wave with other resonant structures were well understood from the view point of phase evolution.

Secondly, we moved from linear optics the nonlinear plasmonic optics and tried to understand how the plasmon enhancement acts on the nonlinear optical processes. In the first example, plasmon enhanced third harmonic generation (THG) on one dimensional gratings was experimentally demonstrated by integrating the nonlinear active medium into the plasmonic devices. Later, the generation of THG vortex beam was also realized by introducing hologram based plasmonic design. Lastly, we re-examined a conventional symmetry problem in nonlinear molecular optics. It was found that the metacrystal, consisting of plasmonic molecule with feature size much larger than conventional molecules, also follows the conventional selection rules

of third harmonic generation.

We believe the knowledge we accumulated in this work also provides a strong background for our future studies on ultra-fast plasmonic switching, in which the all-optical low loss, optical switch can be realized by using the engineered optical properties of plasmonic devices.

# Acknowledgements

I would like to thank my principle supervisor Prof. K. W. Cheah, for his great support and patient guidance in the past few years. I want to thank Prof. S. Zhang, who is my supervisor during my exchange study in University of Birmingham, for his great instructions, ideas and supports. Also, I would like to thank my co-supervisor Prof. S. K. So for his supports in thin film fabrication.

I want to give my thanks to Dr. G. X. Li for his generosity in sharing research skills and experimental experience. Thanks to Prof. Y. B. Pun and Dr. Polis W. H. Wong in City University of Hong Kong for sharing their experiment instruments and resources.

Moreover, I would like to thank all the group members in our group like Dr. T. H. Lam, Dr. K. F. Li, Miss Amy Ching and Mr. Stanley for their sharing in experiment skills. Thank to the research members in Prof. Zhang's group like Dr. Jensen Li, Dr. X. Z. Chen, Dr. L. L. Huang and Mr. Mark Lawrence for their supports during my visit period.

At last, I would like to thank my parents for their long time supports and understanding.

# Table of Contents

<b>Declaration</b>	<b>i</b>
<b>Abstract</b>	<b>ii</b>
<b>Acknowledgements</b>	<b>iv</b>
<b>List of Figures</b>	<b>viii</b>
<b>Chapter 1 Introduction</b>	<b>1</b>
1.1 Surface Plasmon . . . . .	2
1.1.1 Plasmonic and Phase Information . . . . .	3
1.1.2 Plasmonic Sensor . . . . .	4
1.1.3 Plasmonic and Energy Harvesting . . . . .	5
1.1.4 Plasmonic and Gain Medium . . . . .	6
1.2 Plasmonic Cavities and Rabi Splitting . . . . .	8
1.3 Nonlinear Optics in Plasmonics . . . . .	11
1.4 Plasmonic Metasurface . . . . .	14
1.4.1 Optical Spin Hall Effect . . . . .	14
1.4.2 Generation of Optical Vortex . . . . .	15
1.5 Our Work . . . . .	18
<b>Chapter 2 Theoretical Background</b>	<b>20</b>
2.1 Surface Plasmon Polaritons . . . . .	20
2.1.1 Dispersion Relation of Surface Plasmon . . . . .	20
2.1.2 Excitation of SPPs . . . . .	22
2.1.3 Damping Coefficients . . . . .	24

2.2	Nonlinear Optics . . . . .	26
2.2.1	Nonlinear Polarization and Susceptibility . . . . .	26
2.2.2	Second Harmonic Generation and Third Harmonic Generation . . . . .	28
2.3	Generation of Optical Vortex . . . . .	30
<b>Chapter 3 Experimental Methods</b>		<b>32</b>
3.1	Nano-fabrication . . . . .	32
3.2	Thin Film Deposition . . . . .	33
3.3	Ellipsometry . . . . .	34
3.4	Nonlinear Optical Experiments . . . . .	35
<b>Chapter 4 Plasmonic Resonance of Ellipticity on Gold Grating</b>		<b>37</b>
4.1	Introduction . . . . .	37
4.2	SPPs Resonance on Gold Grating . . . . .	38
4.2.1	Analytical Model of Ellipticity of SPPs resonance . . . . .	39
4.3	Ellipticity in Amplitude and Phase Domain . . . . .	41
4.4	Summary . . . . .	44
<b>Chapter 5 Efficient Energy Exchange via Rabi Splitting in Plasmonic Nanocavity</b>		<b>46</b>
5.1	Introduction . . . . .	46
5.2	Plasmonic Fabry-Perot Cavity . . . . .	47
5.3	Rabi Splitting in Plasmonic Cavity . . . . .	50
5.4	Efficiency Energy Exchange Between Plasmonic and Cavity modes . . . . .	57
5.5	Summary . . . . .	59
<b>Chapter 6 Nonlinear Optics and Hybrid Plasmonic Crystals</b>		<b>60</b>
6.1	Surface Plasmon Enhanced Third Harmonic Generation in Plasmonic Crystal . . . . .	61
6.1.1	Introduction . . . . .	61
6.1.2	Gold-Polymer Hybrid Plasmonic Structure . . . . .	61

6.1.3	Efficiency of THG . . . . .	65
6.1.4	Summary . . . . .	69
6.2	Third Harmonic Generation of Optical Vortices Using Holography Based Gold - Fork Microstructure . . . . .	71
6.2.1	Introduction . . . . .	71
6.2.2	Device Configuration . . . . .	71
6.2.3	Linear Optical Experiment . . . . .	72
6.2.4	Nonlinear Optical Experiment . . . . .	74
6.2.5	Summary . . . . .	79
6.3	Conclusion . . . . .	79
<b>Chapter 7 Symmetry-Selective Third-Harmonic Generation from Plas-</b>		
<b>monic Metacrystals</b>		<b>81</b>
7.1	Introduction . . . . .	81
7.2	Nonlinear Optics Experiments . . . . .	83
7.3	Calculation of near field Polarizations . . . . .	90
7.4	Summary . . . . .	92
<b>Chapter 8 Conclusion and Future Work</b>		<b>93</b>
<b>Bibliography</b>		<b>95</b>
<b>Curriculum Vitae</b>		<b>115</b>