Nanophotonics

Manipulating Light with Plasmons

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Preface

Manipulation of light at the nanometer scale is highly pursued for both fundamental sciences and wide applications. The related studies are within the scope of nanophotonics. The diffraction limit of light sets the limit for the smallest size of photonic devices to the scale of light wavelength. Fortunately, surface plasmons (SPs), collective oscillations of electrons at the surface of metal (mostly gold and silver) nanostructures, make it possible to squeeze light into nanoscale volumes and realize light manipulation beyond the diffraction limit.

SPs were discovered and formally named more than a half century ago, although the phenomena related to SPs appeared much earlier. They attracted renewed interest, and there was explosive growth in the 21st century due to the developments in nanostructure fabrications, characterizations, and simulations. The studies on SPs have formed a booming research field called plasmonics, which is concerned with the phenomena, mechanisms, devices, and applications based on SP resonances mostly in metallic and composite nanostructure systems.

Historically, two plasmon-related research topics predate the prosperity of plasmonics, surface-enhanced Raman scattering (SERS) and surface plasmon resonance (SPR) sensing. SERS, discovered in the 1970s, is caused by SP-induced electromagnetic field enhancement. Especially, the hugely enhanced electric field in the nanogap of a nanoparticle dimer reported in 1999 reveals clearly the mechanism of single-molecule SERS and demonstrates the most charming character of SPs in coupled metal nanostructures. The field enhancement effect in nanogaps has been widely used to enhance various light–matter interactions. The SPR sensing developed in the 1980s utilizes the SP resonances of metal films deposited on glass substrates. Their high sensitivity to the environmental change and easy fabrication procedure bring about the commercial application of SPR sensor chips.

Plasmon-based nanophotonics has potential applications in many fields, such as information technology, biological/chemical sensing, medical diagnosis and therapy, renewable energy, and super-resolution imaging. Field confinement beyond the diffraction limit enables the scaling down of photonic devices and facilitates the integration of nanophotonic devices with nanoelectronic devices. Due to its various potential applications, plasmonics attracts researchers in different fields, including physics, materials, biology, chemistry, and medicine, which makes plasmonics a truly interdisciplinary field.

The continuingly emerging research topics bring vitality to this field. For example, quantum plasmonics is developing quickly. On the one hand, quantum effects occur when the size of the nanogap is decreased to a few angstroms. On the other hand, quantum optics phenomena, such as quantum entanglement and quantum interference, are realized in plasmonic systems. Graphene plasmonics extends the plasmonic materials from metal to novel 2D materials. Plasmons have been involved in the studies of chemical reactions, leading to the creation of a new field, plasmochemistry. Plasmonic circular dichroism and various chiral and vortical effects form the field of chiral plasmonics. Photonic spin–orbit interactions and resulting novel optical phenomena in plasmonic nanostructures have been investigated recently.

This book gives a general introduction to the fundamental aspects of plasmonics. Chapter 1 presents a brief introduction to the fundamentals of localized SPs and propagating SPs and outlines the most active research topics. In Chapter 2, the computational approaches to light scattering due to SP resonances in metal nanoparticles are introduced. Chapters 3–5 cover three of the typical subfields resulting from SP resonances in metal nanoparticles: SERS, plasmonic nanoantennas, and plasmon-assisted optical forces. Chapter 6 focuses on propagating SPs in nanowire waveguides for controllable subwavelength light guiding and potential circuitry applications. Chapter 7 introduces the optical properties in plasmonic systems with gain materials.

Plasmonics is still developing fast, and new research topics keep emerging. This book is not intended to cover all aspects of plasmonics but gives some introduction to the fundamental and representative properties and research in this field, which can help graduate students and researchers get a quick study of this field and get the necessary information to step toward new research.

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