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Photon Management Assisted by Surface Waves on Photonic Crystals

POLITECNICO DI TORINO

Springer

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ISSN 2509-6796 ISSN 2509-7024 (electronic)
PoliTO Springer Series
ISBN 978-3-319-50133-8 ISBN 978-3-319-50134-5 (eBook)
DOI 10.1007/978-3-319-50134-5

Library of Congress Control Number: 2016960024

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

A Deliana, compagna di una vita.

Acknowledgements

This book is the summary of 3 years of work and during this period I met several people that somehow influenced the outcome of my Ph.D. activity, directly or indirectly. Nevertheless, I would like to mention here some of the people who have been fundamental for the results I achieved.

A special thanks goes to Prof. Emiliano Descrovi, who has believed in me since the beginning and has always pushed me to do my best. Basically he taught me everything I know about optics and photonics, and our discussions have always been inspirational for me. It is quite fair to say that this work is also his work.

Dr. Natascia De Leo, Dr. Luca Boarino, Dr. Emanuele Enrico and all the people at INRIM for their constant essential technological support.

My mother, for her discrete and constant presence. I know you can understand my mood even 1000 km far away, without any need for many words. Thanks.

My father, who has been providing me everything I needed along all these years.

At last, I would like to thank her who has always believed in me, keeping in spurring me to do always my best. This book is dedicated to you.

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Introduction

In the recent past, the emerging field of nanotechnologies has stimulated intense research efforts, since it holds promise for opening new scenarios in a wide variety of fields. Although *"this field [...] will not tell us much more about fundamental physics,"* as stated by Feynman in 1959, *"it might tell us much more about all the strange phenomena that occur in complex situations. Furthermore [...], it would have an enormous number of technical applications."* As expected by Feynman, fifty years later, nanotechnologies have become pervasive in almost all the research fields, from biology to medicine, from materials science to information technologies just to give few examples.

Within the world of nanotechnologies, nanophotonics and, more generally, technologies devoted to the manipulation of light have gained relevance in several fields. The conversion of far-field electromagnetic radiation into localized energy and vice-versa, as well as the control of the radiation angular pattern of energy emitted by localized sources, is of outstanding relevance in a wide variety of fields.

In the radio frequency regime, for example, a plethora of applications make use of antennas to transmit and receive information, from satellite communications to mobile phones. The extension of such approach to the visible range of frequencies has led to develop the novel concept of optical antennas.

A general argument in antennas theory is the scalability of parameters; that is, the antenna parameters are determined by the wavelength of incident radiation. For a long time, the main challenge in designing antennas for visible light has been related to fabrication capabilities, since the typical size of an optical antenna should be of the order of tens of nanometers, with a resolution of few nanometers.

Thanks to the development, during the last decades, of nanofabrication techniques such as electron-beam lithography (EBL) or focused ion beam (FIB) lithography, a wide variety of optical antennas have been proposed in the recent past, based on dielectric and metallic nanostructures. Particular attention have gained the metallic ones, since the exploitation of surface plasmon resonances (SPRs) allows for confining the electromagnetic field in deep subwavelength volumes and allows for controlling the radiation patter, making such structures effective optical antennas. Moreover, SPRs are localized at the interface between a metal and a dielectric medium, making them suitable as transducers for environment variations and allowing an easy integration of photon sources with the antenna itself. Unfortunately, SPR relies on the oscillations of free electrons in metal, and it is therefore intrinically affected by the scattering of electrons with metallic ions. The scattering results in ohmic losses that lower the performances of SPR-based devices.

Another strategy widely explored to control the light propagation is the exploitation of dielectric materials properly designed, also known as photonic crystals (PCs). Photonic crystals are periodic dielectric structures whose periodicity is comparable with the electromagnetic wavelength. Due to low intrinsic losses in dielectric materials at the visible wavelengths, photonic crystal resonators show narrow resonances with quality factors that can be orders of magnitude higher compared to metallic resonators. For this reason, PCs are widely used as high-quality cavity resonator, reflectors, or waveguides. Although the propagation of light can be strongly manipulated and finely controlled by means of PCs, the request for deep subwavelength confinement cannot be satisfied by purely dielectric structures, because of the diffraction limit. Moreover, the electromagnetic field is usually buried inside the photonic structures, making it difficult the interaction of the environment with the photonic mode. In the attempt to overcome the limitations of the two approaches, several hybrid metallo-dielectric structures have been proposed, with the aim of integrating the confining and enhancing properties of plasmonic structures with the high quality factors of photonic ones.

In this work, I will discuss the use of purely dielectric structures as a valuable alternative to metallic thin films sustaining SPRs. Properly designed one-dimensional photonic crystals (1DPCs) can indeed sustain electromagnetic modes localized at the truncation interface of periodic stacks of dielectric thin films. Their phenomenological behavior is similar to surface plasmon polaritons (SPPs) except from the lack of intrinsic ohmic losses which results in higher performances of the resulting device. Other inherent advantages such as the wide tunability in terms of resonant wavelengths and polarization state of the mode will be discussed as well.

Chapter 1 deals with a description of the basic principles underlying the physics of BSWs on 1DPC and with the interaction between BSW and surface structures. In Chap. 2, the interaction of spontaneous emitters with the photonic environment is discussed. Chapter 3 deals with a particular surface structure, i.e. a ring antenna, which is capable of focusing light, and redirects luminescence coming from localized sources into a collimated beam.