

Preface

Nanostructures can have quite amazing linear and especially nonlinear optical properties. Metallic nanoparticles, for instance, can localize visible light on a scale of a few nanometers only in the form of surface plasmon excitations. This light localization is of key importance for a plethora of fundamentally relevant applications ranging from cancer therapy and water splitting or photocatalysis in general to single molecule (bio-)sensing. When using such nanoparticles for localizing femtosecond light pulses, local field intensities are easily reached that are sufficient to generate high harmonic radiation or to propel electrons out of these particles, generating new nanoscale sources of femtosecond electron bunches of potential interest for future applications in ultrahigh time-resolution electron microscopy or diffraction. Semiconductor nanoparticles offer particularly strong optical nonlinearities and are key elements in next generation light emitting diodes and nanolasers. Moreover, they are of prime interest as biolabels. When combined with metallic nanostructures, new functionality arises, as the strong optical dipole coupling between semiconductor excitons and metal plasmons forms short-lived hybrid polariton excitations that may be useful in ultrafast switching applications or for designing new classes of photonic transistors with unprecedented sensitivity. Polymeric nanomaterials are not only forming the basis of organic photonics. When illuminated with focused femtosecond laser pulses, multiphoton polymerization is induced and this is the basis for sculpting three-dimensional structures with a spatial resolution of 100 nm or even below.

Driven by these and other exciting potential applications, nonlinear nano-optics is an extremely rapidly developing field of research in photonics. It is the aim of this small book to provide an insight into some of the current activities in this emerging field. The idea of the book was born at the 2nd International Workshop on “Nonlinear Nanostructures for Ultrafast Laser Applications” at Max-Born-Institute in Berlin 2011, which succeeded an earlier meeting with a tighter focus on ZnO and TiO₂ nanostructures. These events brought together some of the leading experts in nonlinear nanophotonics and stimulated the exchange of ideas and results on further conferences and meetings, e.g., in the community of laser-induced periodic surface structures, and in joint research projects of some of the authors.

A book project on this extremely fast developing field is inevitably faced with the difficulty of a strict selection. The editors decided to include 14 chapters covering experimental as well as theoretical studies in three different divisions: *Laser-Induced Nanostructures*, *Nonlinear Nano-Optics*, and *Advanced Theoretical Studies*. The spectrum of the contributions addresses some of the topics discussed at the Berlin Workshop as well as very recent continuing activities.

In the first division, Varlamova et al. give an overview of the self-organized pattern formation upon femtosecond laser ablation of dielectrics, and Kazansky et al. introduce the exciting prospects of polarization-shaped laser pulses for laser writing in dielectrics. Also, the remaining four chapters in this division focus on laser-induced writing in semiconductors: *Silicon* (Richter et al.), *TiO₂* (Kumar Das et al.), *dielectrics* (Höhm et al.), and *metals* (Sakabe et al.).

The second division gives a broad overview of recently emerging applications in nonlinear nano-optics. Vogelgesang et al. start by introducing the very interesting optical properties of polariton excitations in strongly coupled metal/semiconductor nanostructures. Kabouraki et al. explain how to sculpt almost arbitrary three-dimensional nanostructures with sub-100 nm precision by multiphoton polymerization. Hentschel et al. give a clear presentation of the surprising success of a nonlinear oscillator model in quantitatively predicting nonlinear optical spectra of plasmonic nanoantennas. The part *Photoemission and Nonlinear Spectroscopy* in this division starts with a chapter by Herink et al., introducing recently discovered phenomena in strong field emission of electron pulses from sharp gold tips. It is followed by a presentation by Kumar Das et al. comparing linear and nonlinear optical properties of zinc oxide nanorods, and an article by Messaoudi et al. on using laser-written periodic nanostructures in metals for surface-enhanced Raman sensing of biomolecules.

The third division summarizes recent theoretical developments in this field. Manley et al. give a concise overview of the optical properties of metallic nanoparticles, their numerical simulation, and possible applications in plasmon-enhanced solar cells before, in the final chapter, Husakou et al. present a fundamentally interesting analysis of laser-driven high harmonic generation in various metallic nanoantennas.

We trust that this small collection of chapters gives an interesting overview of the current status of research in nonlinear nano-optics and will stimulate the reader to dig deeper into the rapidly growing original literature in this emerging field. We also hope that it provides a firm idea of how much more fundamental and applied research is urgently needed to uncover the full potential of nonlinear nano-optics in such diverse areas as physics, chemistry, materials science, measurement technology, and biomedicine.

We close this preface by expressing our sincere thanks to the German Ministry of Education and Research (BMBF) and to all other sponsors for financial support of this meeting and to all coauthors of this book for their important contributions to

this book. Very special thanks are also due to Claus Ascheron from Springer for his expert editorial advice and to Prof. Thomas Elsässer for very substantial support and the generous hospitality at Max-Born-Institute. Most of all, we are very grateful for having experienced the spirit of a fruitful and inspiring collaboration with colleagues from many parts of the world.

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Progress in Nonlinear Nano-Optics

Sakabe, S.; Lienau, C.; Grunwald, R. (Eds.)

2015, XXI, 273 p. 137 illus., 44 illus. in color., Hardcover

ISBN: 978-3-319-12216-8