Graphene Photonics

Understand the fundamental concepts, theoretical background, major experimental observations, and device applications of graphene photonics with this self-contained text. Systematically and rigorously developing each concept and theoretical model from the ground up, it guides readers through the major topics, from basic properties and band structure to electronic, optical, optoelectronic, and nonlinear optical properties, and plasmonics and photonic devices. The connections between theory, modeling, experiment, and device concepts are demonstrated throughout, and every optical process is analyzed through formal electromagnetic analysis.

Suitable for both self-study and a one-semester or one-quarter course, this is the ideal text for graduate students and researchers in photonics, optoelectronics, nanoscience and nanotechnology, and optical and solid-state physics, working in this rapidly developing field.

Jia-Ming Liu is Distinguished Professor of Electrical and Computer Engineering, and Associate Dean of the Henry Samueli School of Engineering and Applied Science, at the University of California, Los Angeles. He is the author of *Principles of Photonics* (Cambridge University Press, 2016), and *Photonic Devices* (Cambridge University Press, 2005), and a fellow of the Optical Society of America, the American Physical Society, the IEEE, and the Guggenheim Foundation.

I-Tan Lin is a hardware engineer at Intel, and his current research interests include graphene-based optoelectronics, terahertz frequency devices, and plasmonics.

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JIA-MING LIU
University of California, Los Angeles

I-TAN LIN
Intel

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Preface

Graphene is a single-layer crystal of carbon. It has unique electronic and photonic properties, as well as unusual mechanical and thermal properties. As the thinnest two-dimensional material, graphene has a nanostructure that can be integrated with various devices and systems, offering the opportunity to transform devices and systems in many areas. Intensive research on graphene started only after it was first isolated in 2004. Since then, graphene has become one of the most studied materials. It has opened up many new fields of scientific research and technological development, which continue to expand rapidly today. Research and development in these young fields promise to revolutionize electronics and photonics technologies in addition to creating new graphene-based technologies.

Graphene has a unique hexagonal crystal structure of two carbon atoms per unit cell. Intrinsic graphene is a semiconductor of zero bandgap, with its charged carriers behaving like Dirac fermions of zero mass, resulting in many extraordinary properties that are very different from those of other materials. Such properties can be controllably modified by proper impurity doping or by electrical or optical modulation, making graphene extremely attractive for novel device applications. The salient electronic and photonic properties of graphene, together with its unique nanostructure, offer innovative opportunities for many potentially revolutionary applications in high-speed/high-frequency electronic and photonic devices, terahertz oscillators and sensors, and ultra-fast nonlinear optical elements.

This book aims to systematically cover the subject of graphene photonics in an organized and comprehensive manner by guiding the reader through fundamental concepts, the theoretical framework, existing experimental observations, and many demonstrated device applications. As such, it starts by describing the basic properties, band structure, and electronic properties of graphene in the first two chapters to lay the necessary foundation for discussions on the optical properties, optoelectronic properties, and nonlinear optical properties of graphene in the following three chapters. Because graphene is a truly two-dimensional system that can serve as a conductor at frequencies up to the terahertz region, it naturally has unique plasmonic properties. Discussions on plasmonics based on graphene are given in a following chapter. The final chapter gives an overview of the graphene-based photonic devices that have been developed or proposed to date.

The development of each concept and theoretical model is thorough and rigorous. Nonetheless, the approach is systematic and often pedagogical for the reader to easily

follow. The theoretical models of the various properties are described and developed through rigorous quantum mechanical formulations and calculations, usually through both semiclassical and full quantum mechanical approaches. Every optical process is analyzed through formal electromagnetic analysis. Detailed figures are used to illustrate the concepts, theoretical results, and experimental measurements. As such, this book is useful to both researchers and students. The required background for a good understanding of this book includes basic concepts of solid-state physics, a solid foundation of quantum mechanics, a firm grounding in electromagnetic wave and fields, and a basic knowledge of physical optics.

This book is primarily aimed at researchers, technologists, and graduate students in the fields of photonics, electronics, nanoscience, nanotechnology, optical physics, solid-state physics, and materials science. It can be used as a reference or a guide to facilitate self-study for these readers. This book is also useful as a textbook for a one-semester or one-quarter graduate course on the specific topic of graphene photonics because it is written such that the concepts are systematically developed from the ground up and it is self-contained. A course utilizing this text would ideally be targeted toward beginning graduate students who have the required background knowledge as described above, though advanced undergraduate students with the required background could also attend.

This book was developed through our research on graphene photonics over the past 12 years. We would especially like to express our gratitude to Kuang-Hsiung Wu and Chih-Wei Luo of National Chiao-Tung University for their friendship and efforts in our collaborative research on graphene photonics. We would like to thank our editor, Julie Lancashire, for her help in the publication of this book. We would also like to thank Vida Liu for creating an original oil painting for the cover art.