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MID-INFRARED COHERENT SOURCES AND APPLICATIONS

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PREFACE

Coherent sources of mid-infrared (mid-IR) radiation are of great interest for a wide range of scientific and technological applications from spectroscopy and frequency metrology to information technology, industrial process control, photochemistry, photobiology and photomedicine. The mid-IR spectrum, which may be defined as wavelengths beyond ~2 μm, covers important atmospheric windows, and numerous molecular gases, toxic agents, air, water, and soil pollutants, components of human breath, and several explosive agents have strong absorption fingerprints in this region. The development of practical coherent solid-state sources in the mid-IR can thus provide indispensable tools for a variety of applications in environmental monitoring and pollution control, detection of water and soil contaminants, food quality control, agriculture and life sciences, and non-invasive disease diagnosis and therapy through breath analysis. Coherent mid-IR sources also offer important technologies for atmospheric chemistry, free-space communication, imaging, rapid detection of explosives, chemical and biological agents, nuclear material and narcotics, as well as applications in air- and sea-born safety and security, amongst many. The timely advancement of coherent mid-IR sources is, therefore, vital to future progress in many application areas across a broad range of scientific, technological, and industrial disciplines.

On the other hand, more than 40 years after the invention of laser, much of the mid-IR spectrum still remains inaccessible to conventional lasers due to fundamental limitations, most notably a lack of suitable crystalline laser gain materials. This has confined the spectral range of conventional solid-state lasers mainly to wavelengths below ~3 μm, resulting in a severe shortage of coherent laser sources at longer wavelengths, and presenting a major obstacle to the widespread advancement of mid-IR science and technology. At the same time, alternative technologies for the generation of mid-IR radiation have been proposed, devised and developed, with the goal of overcoming this persistent barrier. In particular, over the past decade, there have been major new developments in mid-IR sources, driven by the emergence of a number of new technologies and continuing innovations and refinements in many of the more established techniques. Advances in material science, crystal growth, and semiconductor material processing have led to the realisation of a new generation of coherent mid-IR sources based on novel operating principles such as quantum cascade lasers, new types of semiconductor lasers, as well as novel diode-pumped crystalline and fiber lasers based on new solid-state laser gain materials and structures. At the same time, there has been unprecedented progress in some of the more traditional technologies for mid-IR generation, in particular nonlinear frequency conversion and parametric sources, brought about by breakthroughs in nonlinear materials, innovative device design concepts and ongoing advances in pump laser technology. The advent of a new generation of birefringent, quasi-phase-matched, doped, waveguide, fiber and semiconductor nonlinear materials together with novel solid-state, semiconductor, and fiber pump lasers have led to the development of new frequency conversion and parametric sources for the mid-IR with previously unattainable performance capabilities. The ongoing progress in related technologies including synchrotron, free-electron and gas lasers, as well as novel techniques for terahertz (THz) generation have also led to further improvements in such radiation sources with enhanced overall operating capabilities. The important advances in mid-IR science and technology have also had a major impact on new application areas, paving the way for the practical deployment of mid-IR sources in spectroscopy, environmental trace gas detection and sensing, life sciences, imaging, safety and security, and photomedicine.

The wide range of mid-IR technologies have proved highly effective in advancing coherent sources in selected spectral regions from $\sim$1 to $\sim$100 μm, and beyond, into the THz region. The various techniques are often competitive, and in many cases complimentary. Some technologies can deliver mid-IR radiation in regions not accessible to others, while suffering from drawbacks of low power, temporal and spectral inflexibility, or high cost. There are important merits and limitations associated with each approach, making a particular technology more favorable for a given set of requirements and applications than others. However, the broad scope and multi-disciplinary nature of mid-IR technology across a wide range of disciplines (from semiconductor physics and laser engineering to nonlinear optics, material science, spectroscopy and biomedicine) has, at the same time, led to the confinement of each technology mainly to its own specialist community, resulting in a lack of connectivity among the different areas. This factor, in addition to the fundamental barriers, has contributed yet another important obstacle to a more timely advancement of mid-IR science and technology.

The aim of this book is to bring into focus this important research area and provide a comprehensive review of the research topics most pertinent to the advancement of coherent mid-IR sources and their applications. The volume brings together contributions from the most eminent international researchers in the field, covering various aspects of mid-IR technology from fundamental principles to materials, systems and applications, and addresses the most important recent advances in the field since the publication of an earlier volume in 2003 (*Solid-State Mid-Infrared Laser Sources*, I. T. Sorokina and K. L. Vodopyanov, Eds., Springer, 2003). A central theme of the present volume is the strong emphasis on the applications of mid-IR sources to emerging areas of science and technology, with no less than 8 out of the 22 chapters dedicated to this topic. These include spectroscopic techniques for trace gas detection and sensing in environmental monitoring, life sciences, safety and security, applications of mid-IR sources in breath analysis and medicine, as well as potential applications in high-intensity and attosecond physics. It is hoped that this volume will also provide added stimulus for further progress in the field, where major challenges still remain and great potential exists for further new breakthroughs. The timely advancement of mid-IR coherent sources will undoubtedly have important implications across a broad range of scientific and technological disciplines and the field promises to remain a fertile ground for further innovation and exploitation in the future.

In preparing the book, we have relied on the timely contribution of the authors, without whose expert insight, motivation and commitment the publication of this volume would not have been possible. We, thus, extend our appreciation to all the authors. We also convey our thanks to Springer for affording us the opportunity to publish this volume and to the editorial and publishing staff, in particular Wil Bruins, for their assistance, organization and efficiency in coordinating the timely preparation and production of the book. We are also grateful to the North Atlantic Treaty Organization for their valuable support of the Advanced Research Workshop on *Mid-Infrared Coherent Sources (MICS) 2005*, Barcelona, Spain, which served as the original impetus for the publication of this volume.

Majid Ebrahim-Zadeh, Irina T. Sorokina
Barcelona, Vienna, October 2006

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