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Laser Filamentation

Mathematical Methods and Models

Springer

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Preface

Optics and Photonics are now recognized as key enabling drivers that impact technologies in a multitude of areas such as communications, imaging, sensing, energy, and even health sciences. This recent declaration by NSF (USA) is based on the observation that optical and in particular laser technology has been developing at a steady rate. The invention of the laser in the 1960s for generating coherent sources of radiation led to the development of intense ultrafast pulses with time durations spanning femtoseconds ($1\,\text{fs} = 10^{-15}\,\text{s}$), the time scale of atomic (nuclear) motion, to the attosecond ($1\,\text{asec} = 10^{-18}\,\text{s}$), the time scale of electron motion in atoms and molecules. Intensities are also approaching or even exceeding the atomic unit (a. u.), $I_0 = 3.5\times10^{16}\,\text{W/cm}^2$, corresponding to electric field strength $E_0 = e/a_0^2 = 5 \times 10^9\,\text{V/cm}$ at the atomic unit of distance in the ground state of the H atom, $a_0 = 0.0529\,\text{nm}$. Such high fields E or equivalently intensities $I = cE^2/8\pi$ produce ionized electrons with ponderomotive energies $U_\text{p}(\text{eV}) = (eE)^2/(4m\omega^2) = (9.33\times 10^{-14})I(\text{W/cm}^2)\lambda^2(\mu\text{m})$, where e, m are electronic charge, mass and ω, λ are the laser frequency and wavelength. Thus, lasers at current available intensities $I = 10^{14}\,\text{W/cm}^2$ and $\lambda = 800\,\text{nm}$ generate free electrons with kinetic energies in the region of $\sim$10 eV and more. The ionization process is considered as perturbative multiphoton ionization, which for low ionization potentials I_p is transformed into a nonperturbative quantum tunnelling ionization and above barrier ionization at high intensities. For the H atom with $I_\text{p} = 13.6\,\text{eV}(0.5\,\text{a. u.})$, tunnelling ionization is defined by the Keldysh parameter $\gamma = (I_\text{p}/2U_\text{p})^{1/2} < 1$ and above barrier ionization occurs for intensities exceeding the critical $I_\text{c} = 1.4 \times 10^{14}\,\text{W/cm}^2$. Thus, at intensities $I \sim 10^{14}\,\text{W/cm}^2$ one is dealing with nonlinear response of single atoms and molecules to laser fields. In macroscopic gaseous molecular media such as the atmosphere, propagation of laser pulses leads to "Laser Filamentation" due to laser-induced nonlinear refractive indices, high-order polarizations, self-focusing, and plasma generation.

This book is based on a workshop, the first of its kind ever held in Canada, and is focused on the nonlinear theoretical and mathematical problems associated with ultrafast intense laser pulse propagation in gases and in particular in air. The chapters in this book are based on lectures by invited speakers, mainly theorists and mathematicians and supplemented by active experimentalists who are acknowledged experts in this new field of nonlinear laser molecule interaction and propagation.

The co-organizers of the workshop especially thank the CRM (Centre de recherches mathématiques) for financial support and its staff for the administrative organization, NSF (USA) with a special grant and AFOSR for partial travel support, and the scientific publisher Springer for publishing the lectures of the invited speakers in this "International Year of Light." We also thank Christiane Rousseau of CRM for introducing this workshop as a new activity in the international UNESCO sanctioned program MPE (Mathematics of Planet Earth) and a new direction in research on weather and climate control via current advanced laser technologies.

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