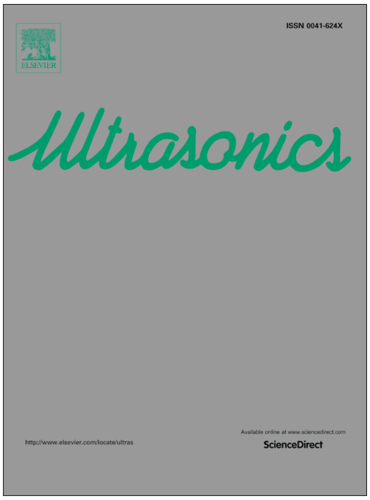

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Laser-induced ultrasonic waveform derivation and transition from a point to a homogeneous illumination of a plate

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Abstract

Ultrasound modeling, being an established practice, is used to study the fundamentals of light-matter interactions. Although much has been published on the matter, pressure and thermal expansion induction mechanisms in laser ultrasonics have rarely been combined, as they should, in a single ultrasonic source while the effects of its size variation have only been shown to a limited extent. In the paper, we unite these light-matter interaction mechanisms, with inclusion of lateral optical forces, into a single laser-stimulated source as it is observed in nature. With a laser pulse as a manipulable source, we simulate the multifaceted workings of light-matter interactions by exposing the distinct transients originating from different source localities as generated by different induction mechanisms. We also present a transition of simulated ultrasonic waveforms in the epicentral point on the surface of a solid plate opposite from the source while it is expanded from a point to a quasi-limitless extent for pressure and thermal expansion generation regimes. The model utilizes geometric probability theory together with Huygens' superposition principle and temporal convolutions to construct the desired waveforms out of individual Green's functions. We show how the ultrasound generation regimes stem out of a single source and how its size together with energy and momentum transfers during the light-matter interactions affect the induced ultrasonic transients.

Keywords: laser ultrasonics, optical forces, radiation pressure, thermoelastic expansion, waveform modeling

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1. Introduction

With thermo-elastodynamic laws generally well understood, with advanced mathematical tools and powerful computing machines, modeling of wave propagation has become an established practice. In ultrasonic research and associated applications, it is essential for interpreting measurements and understanding the underlying physical mechanisms. Due to recent strides in fundamental research, particularly regarding the measuring of light-pressure-induced ultrasound [1, 2] and the so-called Abraham–Minkowski controversy [3, 4, 5, 6, 7, 8, 9, 10, 11], laser ultrasound modeling is gaining a new momentum and a novel aspect in its applicability.

The use of a laser pulse to stimulate an ultrasonic source in elastic media provides the ability to easily control its time profile, spatial distribution, energy, and momentum in much broader ranges than using mechanical ultrasonic sources. An additional and unique aspect of laser ultrasonics is that it provides one of the platforms from which to study the intricacies of light-matter interactions.

While some condensed volumes on the matter in general have been compiled [12, 13, 14, 15, 16, 17, 18], most of the relevant research is mainly scattered in time and throughout literature. One can find, for example, expositions on pressure-induced [19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35] as well as thermal-expansion-induced [26, 27, 28, 29, 30, 31, 32, 33, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44] ultrasound propagation in a half-space [21, 22, 23, 24, 25, 26, 27, 28, 32, 37, 42, 43] or in a large plate [19, 20, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 44] from point [26, 27, 28, 29, 30, 31, 32, 33, 34, 37, 38, 39], areal [20, 21, 22, 23, 24, 25, 35, 36, 40, 41, 42] and quasi-limitless [19, 43, 44] sources to receivers in similar ranges in lateral [19, 37, 42], epicentral [32, 33, 34, 35, 36, 37, 38, 39, 43, 44] or arbitrary [20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 40, 41] relative positions.

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