

## New Applications of the Mössbauer Effect

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**Abstract**—Results from a Mössbauer experiment to observe acoustic oscillations induced by pulsed laser excitation in MgO:<sup>57</sup>Fe<sup>2+</sup> crystal are presented. Time-domain spectra are satisfactorily described by the theory of the frequency modulation of Mössbauer radiation transmitted through a vibrating resonance medium. It is proposed that the  $D_{4\Omega}/D_{2\Omega}$  ratio of the fourth and second Fourier harmonics of the modulated radiation be used to measure the amplitude of nuclear oscillations.

DOI: 10.3103/S1062873817070292

### INTRODUCTION

Mössbauer spectroscopy has been successfully used to obtain information on the microstructure, magnetic ordering, and chemical bonds between resonance atoms and their immediate environments. Among the many other useful applications of the Mössbauer effect that allow us to obtain information about the dynamic processes induced in a target, those of radio-frequency (RF) magnetic fields, ultrasound, and optical radiation hold a special place [1]. Interesting effects of the impact external fields have on resonance nuclei include the ultrasound [2] and magnetostrictive modulation [3–5] of gamma radiation, the RF collapse of magnetic hyperfine structure [6], quasienergy splitting of Mössbauer lines upon the excitation of nuclear magnetic resonance on the ground and excited states of the resonance nucleus [7–9], the rotation of the hyperfine magnetic field on a nucleus [10], and gamma echoes [11]. These phenomena markedly improve the efficiency of applying the Mössbauer effect to study dynamic processes and allow us to obtain information that is inaccessible using traditional experimental schemes.

For example, the ultrasound modulation of the Mössbauer radiation is effectively used to study solid-state ultrasound phenomena [12]; the RF collapse of hyperfine structure allowed the authors of [13] to recover the distribution of quadrupole splittings in alloys of soft magnetic materials; and the quasienergy splitting of Mössbauer lines was used in [14] to determine the strength of alternating magnetic fields on nuclei of resonance atoms and the coefficient of the hyperfine enhancement of an RF field on nuclei in magnetically ordered materials.

At the same time, there has been much interest in studying phenomena induced by laser radiation. This

interest is due to the possibility of extending the concepts of quantum optics with respect to interference effects in multi-level coherently excited electron systems to the regions of nuclear systems and gamma-range radiation [15, 16]. Considerable changes in Mössbauer spectra, including the suppression of the resonance absorption, changes in the width of lines and their shifts, and the emergence of additional lines and the splitting of existing lines were predicted in [15]. Experimental studies performed on optical crystals doped with <sup>151</sup>Eu and <sup>57</sup>Fe nuclei revealed considerable changes in the shape of the Mössbauer spectrum of <sup>151</sup>Eu ions and the emergence of additional hyperfine structure in the case of <sup>57</sup>Fe ions subjected to optical pumping, due to the redistribution of the population of electronic sublevels under the action of resonance laser radiation [16].

Excitation of the solid state by pulsed laser radiation can produce effects associated with the generation of mechanical acoustic oscillations of a studied sample. Different characteristic elastic modes can arise when a pulsed laser beam falls on a solid surface as a function of the depth of radiation penetration, thermal diffusion, the elastic and geometric properties of the material, and the parameters of the laser pulse (e.g., intensity, shape, duration, and focal spot size). The action of high-intensity pulsed laser radiation results in strong thermal and hydrodynamic deviation from the equilibrium state of the irradiated region of the medium [17]. For the average optical energy densities released in the medium, the main factor in generating sound is the thermal expansion of the irradiated volume of the material. Other mechanisms for the optical generation of ultrasound waves in the region of units of GHz and higher using schemes of excitation with crossed pulsed lasers are also known [18].