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Editorial

Editorial for the Special Issue: "Laser Cooling of Solids: Novel Advances and Applications"

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Laser cooling, or refrigeration, is a physical process in which a substance is maintained at a temperature below that of its surroundings. The process dates back thousands of years to when people attempted to preserve their food using ice and snow placed in holes in the ground or in cold cellars. In the 19th century, scientists liquefied the permanent gases and brought cryogenics into existence. In 1929, Pringsheim proposed to use anti-Stokes fluorescence to cool sodium vapor [1]. In his "theoretical" experiment, the sodium vapor in "Dewar 1" was pumped with a filtered sodium vapor lamp in order to excite electrons from the $^2S_{1/2}$ ground state to the first $^2P_{1/2}$ excited state (Figure 1). Inelastic collisions in the gas (thermalization) excite some electrons to $^2P_{3/2}$ excited state. The excited electrons relax to the ground state with resonant and anti-Stokes fluorescence, thus removing energy from the system and causing its refrigeration. This fluorescence has to be quenched by nonradiative relaxation with heat generation in "Dewar 2" filled with the mixture of sodium vapor and nitrogen.

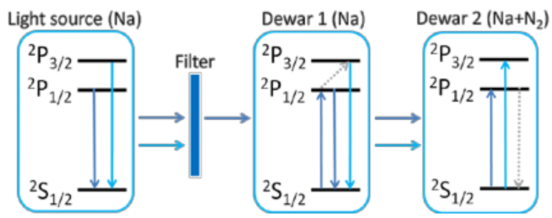

Figure 1. Pringsheim's experiment.

In 1960, the first laser was demonstrated. This groundbreaking scientific achievement has revolutionized optical cooling with anti-Stokes fluorescence. In 1995, optical cooling with anti-stokes fluorescence was demonstrated for a rare-earth-doped solid pumped with a laser [2]; thus, laser cooling of solids with anti-Stokes fluorescence was born. In this first experiment, a high-purity ytterbium (Yb^{3+})-doped fluorozirconate ZrF_4-BaF_2-LaF_3-AlF_3-NaF-PbF_2 (ZBLANP) glass sample was cooled down to only 0.3 K below room temperature. In the last two decades, laser cooling of solids progressed rapidly.

This Special Issue presents the latest advances in laser cooling of solids and its applications in different scientific fields.

The replacement of flash-lamps by laser-diode pumping for solid-state lasers has improved the laser technology. Compared to flash-lamp pumps, the use of laser diodes has led to significant benefits in efficiency, simplicity, compactness, reliability and cost. At the same time, the thermal problem has come into existence for high power lasers. Indeed, in the majority of lasers, heat generated inside the laser medium is an unavoidable product of the lasing process. Different approaches including fiber lasers and thin-disk lasers were developed in order to mitigate heat in lasers. The idea of radiation-balanced (athermal) lasers operating without detrimental heating of laser medium was presented by Nemova G. in review [3]. This new design of optically pumped rare-earth-doped solid-state lasers is based on the principle of anti-Stokes fluorescence cooling of the laser medium. The review is devoted to the history and progress on radiation-balanced lasers with a special focus on rare-earth-doped lasers. Four main designs of athermal lasers including radiation-balanced bulk and fiber lasers, radiation-balanced disk lasers, and athermal microlasers have been considered.

Dobretsova E.A. et al. [4] describe synthesis and laser cooling of 10%Yb^{3+}:$LiLuF_4$ crystals. The 10%Yb^{3+}:$LiLuF_4$ (Yb:LLF) crystals have been synthesized through a safe and scalable polyethylene glycol (PEG)-assisted hydrothermal method. The influence of reaction temperature, time, fluoride source, and precursor amount on the shape and size of the Yb:LLF crystals are discussed in the paper. Laser cooling to more than 15 K below room temperature in air and 5 K in deionized water under 1020 nm diode laser excitation have been demonstrated at a laser power of 50 mW.

New methods for the rapid cooling of solids with increased efficiency have been analyzed and demonstrated experimentally by Andre L.B. et al. [5]. The advances offered by optical saturation, dipole-allowed transitions, and quantum interference for improved laser cooling of solids have been comprehensively discussed in this paper.

Murphy, C. et al. [6] review the derivation of the Bloch-Redfield equation for a quantum system coupled to a reservoir, and its extension, using counting fields to calculate heat current. They use the full form of this equation, which makes only weak-coupling and Markovian approximations, to calculate the cooling power for a simple model of laser cooling.

Two parameters, namely, the external quantum efficiency η_{ext} and the background absorption coefficient α_b, are important for assessing the laser cooling grade of the rare-earth-doped materials. A promising method for measuring of these crucial parameters has been presented by Duan X. et al. [7]. After calibration, the temperature resolution of the thermal camera was better than 0.1 K.

To conclude, this Special Issue, "Laser Cooling of Solids: Novel Advances and Applications", includes research and review papers that present the latest achievements on the subject. The data presented may be of great interest for a better understanding and application of the laser cooling of solids based on anti-Stokes fluorescence.

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Short Biography of Author

Dr. Galina Nemova is a research fellow at Polytechnique Montréal. She received her M.Sc. and Ph.D. degrees from the Moscow Institute of Physics and Technology. Dr. Nemova is a Senior Member of Optica, formerly the Optical Society of America. She has edited two books and authored more than 100 papers. She is the author of *Field Guide to Laser Cooling Methods* (2019) *and Field Guide to Light–Matter Interaction* (2022). Her research interests cover a broad range of photonics topics, including rare-earth-doped materials, nanophotonics, fiber lasers and amplifiers, Raman lasers, nonlinear optics, and laser cooling of solids.