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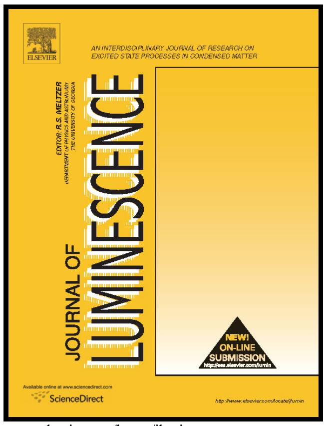

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Efficient luminescence extraction strategies and anti-reflective coatings to enhance optical refrigeration of semiconductors

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Abstract

Laser refrigeration of solids has emerged as a viable solution for vibration-free and compact cooling that does not require any moving parts or cryogenic liquid. So far, rare-earth doped glasses are the only bulk materials that have provided efficient laser cooling based on the anti-Stokes process. These materials have low indices of refraction and are suitable for efficient luminescence extraction. However, up until this date, laser cooling of bulk semiconductors has not been achieved. One major challenge that needs to be addressed is the photoluminescence trapping and the consequent photon recycling. In this paper, we explain various methods to enhance light extraction for the purpose of laser cooling. We specifically provide guidelines for design and fabrication of graded index and subwavelength structures to maximize the extraction efficiency. Furthermore we present novel techniques for increasing the external quantum efficiency and enhancing the overall laser cooling efficiency.

1. Introduction

Luminescence extraction from materials has been one of the most important issues in optics over the past decades. In many fields of research such as biology, energy-saving solid-state devices (such as light emitting diodes and solar cells) and photonic devices, efficient coupling of light across different media is required to achieve sufficiently sensitive, accurate, and fast optical functionalities and to increase the efficiency of energy conversion. Light emission and absorption are dependent on the internal chemical and physical characteristics of the material as well as its structural characteristics that determine the coupling of the light from the active medium to the outside world [1-5]. In this regard, various techniques have been attempted to increase light coupling. These methods rely on surface modifications, deposition of anti-reflective (AR) coatings, or changes of the size and shape of the material in order to enhance the light coupling. Here, we review the main strategies for increasing light extraction and outline their advantages and drawbacks in the context of optical refrigeration of semiconductors. However, many of the strategies detailed here could be directly used in the aforementioned fields.

Laser cooling has emerged as a vibration free, robust and compact technique of cooling that can achieve temperatures below 100 K,[6] clearly surpassing its technological counterpart, the thermoelectric cooler, which at best reaches ~170 K[7]. Various techniques to refrigerate solids with lasers have been

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