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Characteristics of hybrid laser cooling of Yb-doped nanocrystals

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The field of optical cooling concerns many areas of current scientific research, among which are quantum simulation [1], frequency standards [2], Bose-Einstein condensation [3], atom optics [4]. Recent studies often focus on the cooling of various nanoparticles and nanoclusters using cavity cooling [5], feedback cooling [6], and laser cooling based on resonant transitions in impurities [7]. The application of deep optical cooling that arouses the most interest is the obtaining of macroscopic quantum states, in which the de Broglie wavelength of a nanoparticle becomes comparable with its size [8].

Recently we suggested the scheme of optical cooling of Yb-doped nanocrystals, which combines a quadruple radio-frequency trap (RFT) with coherent population transfer in Yb impurities. We considered two cases of this transfer, namely, ultraviolet (UV) Raman pulses [8] and time-separated UV optical excitation referred to as Stimulated Raman Adiabatic Passage (STIRAP) [9]. These approaches demonstrate the possibility to cool both the center-of-mass (COM) motion and the phonon modes of a 100 nm Yb-doped fluorite nanocrystal. However, coherent population transfer techniques are limited by infrared (IR) feedback loop, which inevitably introduces additional heat to the system while monitoring the location of a nanocrystal within the RFT. This disadvantage is not present in the Doppler-like noncavity cooling [7], which utilizes RFT localization and continuous IR illumination and allows to efficiently reduce external temperatures of Yb-doped nanocrystals.

In this work we continue to investigate the deep IR cooling of a Yb-doped fluorite nanocrystal in RFT. We consider the interaction between nanocrystal's internal and external degreees of freedom. The former are optical phonon modes that are conjugated with the transitions in Yb ions upon Doppler-like cooling, and the latter simply refer to COM motion of nanocrystal. We describe these degrees of freedom as three-dimensional harmonic oscillators [10]. Knowing the features of interaction between nanocrystal's degrees of freedom can sufficiently advance the understanding of processes behind the laser cooling of solid nanoparticles.

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