Improving optical trapping of a single upconverting nanoparticle by plasmonic structure

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Abstract. Upconverting nanoparticles have been used as optical probes in a great variety of scenarios ranging from cells to animal model. A single upconverting nanoparticles can be remotely manipulated by laser in a contactless way. When assessing an optically trapped single nanoparticle, the luminescence intensity and the trapping stability is very limited. We proposed the plasmonic enhancement to improve the luminescence efficiency of a trapped upconverting nanoparticles. The optical trapping force was demonstrated to be improved simultaneously.

1 Introduction

The upconverting nanoparticles (UCNPs) are promising particles imaging probes thanks to their unique luminescence properties [1]. They absorb low energy laser and transfer it to higher energy emission. Optical trapping is an accurate technique to achieve precise three-dimensional manipulation of a single particle in an aqueous medium. Optically trapped UCNPs have been extensively used for thermal and chemical sensing. However, it is still challenging to deal with a single nanoparticle. The brightness of a single UCNP is close to the detection limit. The magnitude of the optical force decreases gradually with the particle size decreases, which increases the difficulty of stable nanoparticle trapping. Surface plasmonic structure have the potential to solve these problems. The plasmonic traps provide the potential to enhance the optical force [2]. Results from earlier studies demonstrated that upconverting efficiency can be improved by plasmon resonances, which enhances the brightness of aggregated UCNPs deposited on metallic substrates [3]. Nevertheless, we need to further demonstrate the enhancement on the scale of individual nanoparticle. In this work, we utilize a plasmonic substrate to simultaneously enhance the luminescence intensity of a single UCNP and trapping stability.

2 Materials and methods

An Au-patterned substrate was used as the plasmonic structure in this work, as shown in Fig.1(a) The size of Au Island is 96 ± 9 nm. Figure. 1(b) shows the Tm^{3+} doped UCNPs ($NaYF_4$: 25% Yb^{3+}, 0.3% Tm^{3+}@$NaYF_4$) with a size of 41 nm. They can strongly absorb the 980 nm laser and converts it to visible emission.

As shown in Fig. 2, a 980 nm laser served to optically trap, excite upconverting luminescence, and excite the surface plasmons (SPs). The Au-patterned substrate was used to generate SPs. A single UCNP was optically trapped on both glass and Au-patterned substrates. The luminescence intensity and optical force were measured when the trapped single UCNP in both cases. The optical force was determined by using the hydrodynamic-drag method. The luminescence intensity of a single UCNP was determined by the time series of intensity signal. There was a step-like rise when one particle was trapped.

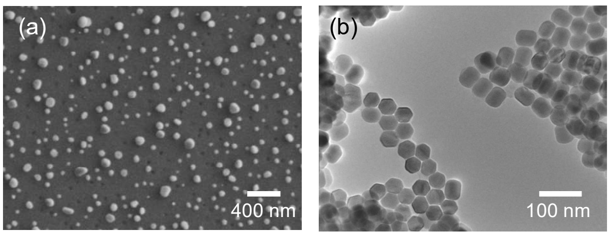

Fig. 1. (a) Scanning electron microscopy image of the Au-patterned substrate. (b) Transmission electron microscopy image of the UCNPs.

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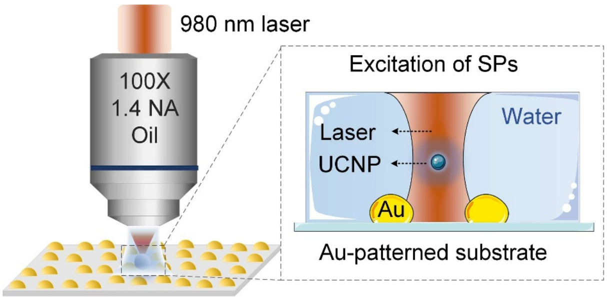

Fig. 2. Schematic of the optically trapped UCNP on top of the Au-patterned substrate.

3 Results and discussion

Experimental results indicate that the luminescence intensity of a single UCNP and the optical trapping force acting on it are simultaneously enhanced by using the Au-patterned substrate. Figure 3 shows the histograms of luminescence intensity obtained from the time series signal when the single UCNPs were trapped on glass and Au-patterned substrates, respectively. The presence of the plasmonic substrate enhances the intensity.

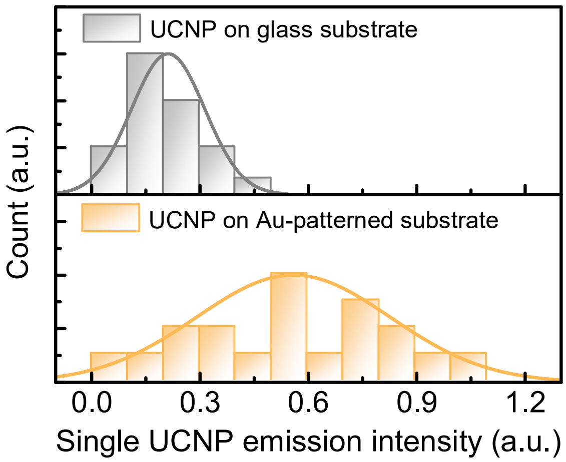

Fig. 3. Luminescence intensity of an optically trapped single UCNP: on the glass substrate (top panel) and Au patterned substrate (bottom panel).

The optical trapping forces were measured at different laser power. As shown in Fig. 4, the laser power dependence of optical trapping force shows a linear trend in both cases. The trapping force acting on an UCNP on the Au-patterned substrate also show a significant increase. The trapping stiffness calculated from the slope of the linear fit increases from 0.39 to 0.74 fN $\mu m^{-1} \cdot mW^{-1}$. The plasmonic enhancement is higher with higher laser power, from 73% to 417%.

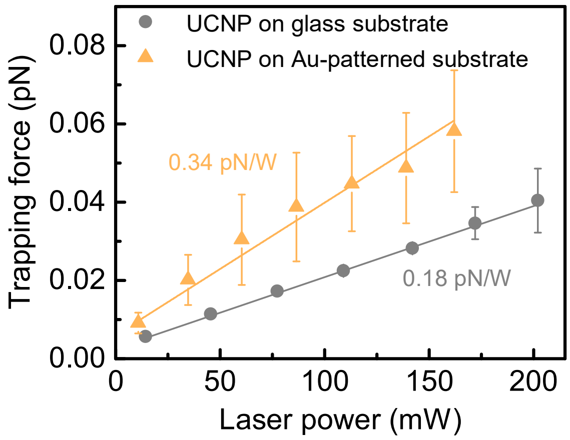

Fig. 4. Laser power dependent optical trapping force acting on the single UCNP on glass and Au-patterned substrate.

4 Conclusions

The optical trapping technique and plasmonic enhancement of intensity we are using are well-known, but the combination of them reveals the new concept that luminescence of a single UCNP can be improved by plasmonic structure. The trapping force acting on it can also be enhanced. This can be effectively used for the development of bright and stable single nanoparticle probe for imaging.

This work was supported by the Ministerio de Ciencia e Innovación de España (PID2019-106211RB-I00, PID2019 105195RA I00, CNS2022-135495, TED2021-129937B-I00), CNPq and FAPESP (2018/22214-6), and FAPESP (2021/08111-2, 2019/12588-9). F. Zhang acknowledges the scholarship from the China Scholarship Council (202108440235).

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