Plasmon-enhanced Upconverting Nanoparticles: A Comparison of Analog and Digital Readout

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Introduction

Upconverting nanoparticles (UCNPs) have unique optical properties for biosensing: background-free detection, sharp emission lines, non-photobleaching, non-blinking and high stability [1]. The main limitation of UCNPs is their relatively low upconversion efficiency, which makes the detection of individual nanoparticles challenging. In this work, we demonstrate diverging surface plasmon polaritons as a mean of imaging single UCNPs. Then, we compare the analog and digital detection of UCNPs.

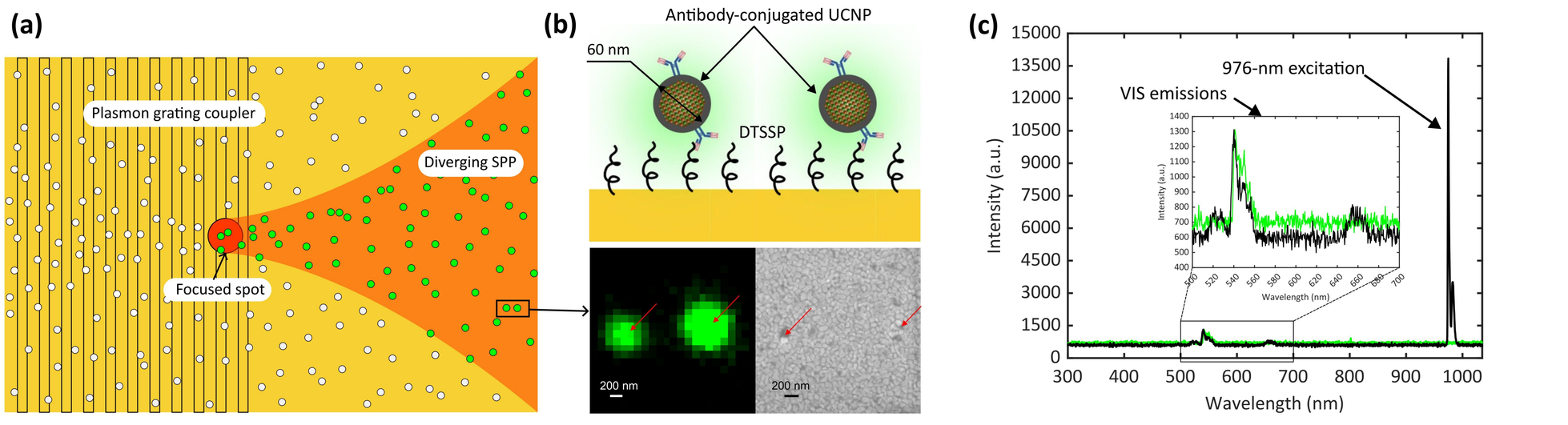

Figure 1. (a) Illustration of diverging surface plasmon polaritons for UCNP imaging. (b) Detection of single UCNP functionalized on the surface [2]. (c) Emission spectrum of UCNPs.

Methodology

Diverging SPPs were excited by a focused Gaussian spot on a plasmon grating coupler with different periods from 840 nm to 940 nm (Figure 1(a)). In Figure 1(b), antibody-conjugated UCNPs (UPCON 540, no. 43-07, $NaYF^4:Yb^{3+}$, Er^{3+}, 36 nm core/12 nm shell, Kaivogen Oy) were functionalized on the gold surface via the covalent bonds between the antibody and DTSSP cross-linkers. Emission spectrum of UCNPs is shown in Figure 1(c).

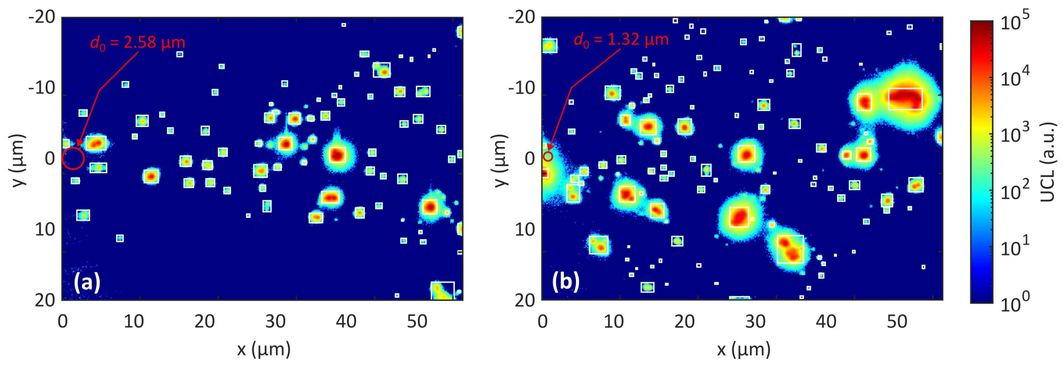

Figure 2. UCNP images obtained using diverging SPPs coupled by a 920-nm plasmon grating coupler with spot diameters of (a) 2.58 µm and (b) 1.32 µm.

In Figure 2, UCNPs can be detected by either analog readout or digital readout. In analog detection, upconversion luminescence intensity was quantified by integrating the pixel intensities across the entire UCNP image. While digital detection counted the number of UCNPs on the image.

Results

Figure 3 compares the variability among ten gratings with the same period for digital and analog detection across different grating periods. Digital detection shows consistently lower variability (lower CVs) than analog detection across all grating periods.

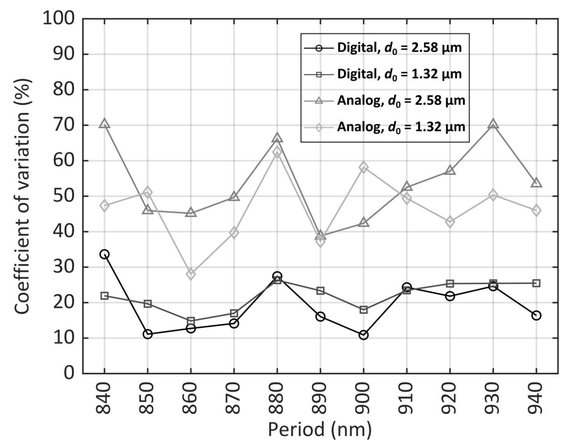

Figure 3. Coefficient of variation of 10 grating elements within each period in digital and analog detection of UCNPs with the 2.58 µm and 1.32 µm focused spots.

Digital counting does not rely on UCL intensity, making it less sensitive to intensity fluctuations arising from variations in SPP coupling efficiency.

Conclusions

- **Plasmon-enhanced imaging enable single UCNP detection**
- **Digital detection is more robust to variations in plasmon-enhanced UCNPs**
- **Digital detection is likely to offer better repeatability when using plasmon-enhanced UCNPs for quantitative biosensing**

References

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2. D. Le, M. Kreivi, S. Aikio, N. Heinilehto, T. Sipola, J. Petäjä, T.-L. Guo, M. Roussey, and J. Hiltunen, "Diverging surface plasmon polaritons for single upconverting nanoparticle imaging," Laser & Photonics Reviews 19(19), e00426 (2025).

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