



# Study of spatial thermal distribution of gold nanourchins in saline by combined transverse probe beam deflection and beam wavefront sensor: biomedical implications

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## Abstract

Combined probe beam deflection (PBD) and wavefront sensor (WFS) technique are used to investigate the thermal distribution of gold nanourchins (GNU) in physiological saline (PS) using a low-power continuous NIR diode laser. Three different samples were prepared for the experiment: (S1) 0.5 mg/mL GNU only, (S2) 0.5 mL PS and 0.3 mL GNU, and (S3) 0.5 mL PS and 0.1 mL GNU. The laser transmission initially increases linearly as  $S3 > S2 > S1$ , but reaches a plateau and remains constant. The probe beam response in an adjective statistics process exhibited a stochastic behaviour at different positions and constant power in *x*- and *y*-directions. The beam view profiles showed a non-uniform intensity distribution and the addition of PS dramatically caused a blue shift indicating its cooling effect,  $S1(20) \text{ warmer} > S1(10) \text{ medium} > S2(20) \text{ cooler}$ .  $S1(10)$ ,  $S1(20)$ , and  $S2(20)$  correspond to the samples irradiated with the laser power (mW) shown in the bracket. The peak-to-valley (PV) and root-mean-square (RMS) values demonstrated a non-linear intensity distribution during the scanning process. The greater PV values in deeper positions may well due to agglomeration, hence the sedimentation process. The Zernike coefficients with high absolute values represent the aberrations that cause the greatest distortion of the wavefront and found in the order of  $S2(20) > S1(10) > S1(20)$ . This is consistent with PV wavefront slope and spatial period aberration relation. The opto-thermal coefficients were obtained as  $S2 (-7.86 \times 10^{-4}) > S3: 0.5 \text{ mL PS and } 0.1 \text{ mL GNU } (-6.3 \times 10^{-4})$ , respectively.

## 1 Introduction

Recently, there have been growing interests in the opto-thermal properties of nanoparticles in a wide variety of industrial and biomedical applications including photonic devices [1], plasmonic devices [2], surface-enhanced spectroscopy [3], biochemical sensing [4], biomedical imaging [5, 6], and photothermal therapy [7–10]. This is mainly because of the unique optical properties of plasmonic nanoparticles (PNP) whose electron density can couple with electromagnetic radiation with wavelengths much larger than the nanoparticle dimension [11]. Upon interaction of the electromagnetic wave with PNP, the conduction band electrons are excited leading to a coherent oscillation which exhibits strong

optical absorption and scattering due to localized surface plasmon resonance (LSPR) [12]. Because of the plasmon oscillation, a dipole is induced which enhances the local electric field at the surface of PNP, and hence, a strong light absorption and scattering occurs at the SPR frequency, which is also temperature-dependent [13]. The absorbance and scattering cross sections describe the intensity of absorbed or scattered light at a given frequency. The heat produced by the PNP is due to the absorption of incident photons and conversion of photon energy into heat energy, and eventually is transferred to the surrounding matrix. It is this process that forms the basis of photothermal application of PNP in biomedical applications [14]. However, depending on the size and the shape of these particles, one can also select appropriate particles for bioimaging where the scattering becomes dominant unlike absorption in the case of heating effect with an exception in the case of photoacoustic where the absorption plays a key role in imaging [15].

In some biomedical applications, the PNP is employed as colloidal particles in liquids (e.g., blood) where factors such as the dispersion quality, agglomeration, and sedimentation are important issues to be considered [16–19]. Another

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