Supporting information for 'Optical manipulation of individual strongly absorbing platinum nanoparticles'

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Supporting Methods

Characterization of the nanoparticles Platinum and gold nanoparticles and gold nanoshells were purchased from Nanocomposix, Czech Republic. The nanoparticles were diluted in milliQ water (1000X) and sonicated. The solutions were filtered through membrane pore sizes of 100 nm for platinum and gold nanoparticles and of 200 nm for gold nanoshells, respectively, to minimize aggregates. The gold nanoshells were purchased with a coating consisting of thiolated 5kD poly ethylene glycol (PEG). A diluted and filtered nano-suspension was loaded into a perfusion chamber consisting of a cover glass and a microscope slide separated by one layer of double sided sticky scotch tape. After a waiting time of ∼10-15 minutes a single NP would diffuse into the trap and remain stably trapped.

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As the optical properties of metallic nanoparticles are strongly dependent on the exact size of the particle the sizes of the particles were quantified by two different methods: (i) The hydrodynamic diameters of the particles in suspension were measured using a Zetasizer Nano Series Dynamic Light Scattering (DLS) machine (Malvern Zetasizer Nano ZS90). (ii) We performed a size analysis based on transmission electron microscopy (TEM) images of all nanoparticle types. The results of these two types of measurements are shown in Supporting Figure S1 and summarized in Supporting Table S1. The TEM images (insets in Supporting Figure S1 a1-d1) show that all particle samples appear relatively homogeneous with spherical particles. The experimentally obtained size distributions obtained from TEM are relatively narrow and symmetric (see Supporting Figure S1 a1-d1) and in reasonable agreement with the Manufacturer given values and the DLS results.

Simulations of optical cross sections and polarizabilities. For the calculations the background incident electric field, $\mathbf{E_{inc}}$, was considered as a plane wave traveling in the positive x direction, with the electric field being polarized along the z axis:

$$\mathbf{E_{inc}} = [0, 0, E_0 e^{-ikx}]. \tag{1}$$

Here, E_0 is the wave amplitude, $k = \frac{2\pi}{\lambda}$ is the wavenumber in water, $\lambda = \frac{\lambda_0}{n}$ is the wavelength in water, and λ_0 and n are the wavelength in vacuum and water's index of refraction, respectively.

The scattering cross section was calculated as:

$$\sigma_{\mathbf{scat}} = \frac{2}{c\epsilon_0 |\mathbf{E_{inc}}|^2} \int\int (\mathbf{n} \cdot \mathbf{S_{scat}}) dS = \frac{1}{c\epsilon_0 |\mathbf{E_{inc}}|^2} \int\int (\mathbf{n} \cdot Re[\mathbf{E_{scat}} \times \mathbf{H_{scat}}^*]) dS \tag{2}$$

where $\mathbf{S_{scat}}$ is the scattered Poynting vector and $\mathbf{n}$ is the normal vector pointing outwards from the closed surface around the scatterer which the integral is taken over.

The absorption cross section was calculated as:

$$\sigma_{\mathbf{abs}} = \frac{2}{c\epsilon_0|\mathbf{E_{inc}}|^2}\int\int\int QdV = \frac{2}{c\epsilon_0|\mathbf{E_{inc}}|^2}\int\int\int \frac{1}{2}Re[\mathbf{J}\cdot\mathbf{E}^* + i\omega\mathbf{B}\cdot\mathbf{H}^*]dV \qquad (3)$$

where, $Q = \frac{1}{2}Re[\mathbf{J}\cdot\mathbf{E}^* + i\omega\mathbf{B}\cdot\mathbf{H}^*]$ represents the electromagnetic power loss density in the particle, $\mathbf{J}$ is the current density, $\mathbf{B}$ is the magnetic flux density and the integral is taken over the volume of the particle.

The sum of the scattering cross section ($\sigma_{\mathbf{scat}}$) and the absorption cross section ($\sigma_{\mathbf{abs}}$) provides the extinction cross section ($\sigma_{\mathbf{ext}}$). The complex polarizability ($\alpha = \alpha_r + i\alpha_i$) of the nano-particles can be calculated from the extracted scattering and absorption cross sections. The complex permittivity of the nanoparticles can be expressed as $\epsilon_r = \epsilon^{'} + i\epsilon^{''}$ where the real and imaginary part of the complex permittivity are deduced from fitting the Brendel-Bormann model to the experimental data.[1]

References

(1) Rakic, A. D.; Djurisic, A. B.; Elazar, J. M.; Majewski, M. L. Optical properties of metallic films for vertical-cavity optoelectronic devices. *Appl. Opt.* **1998**, *37*, 5271–5283.

Supporting Tables

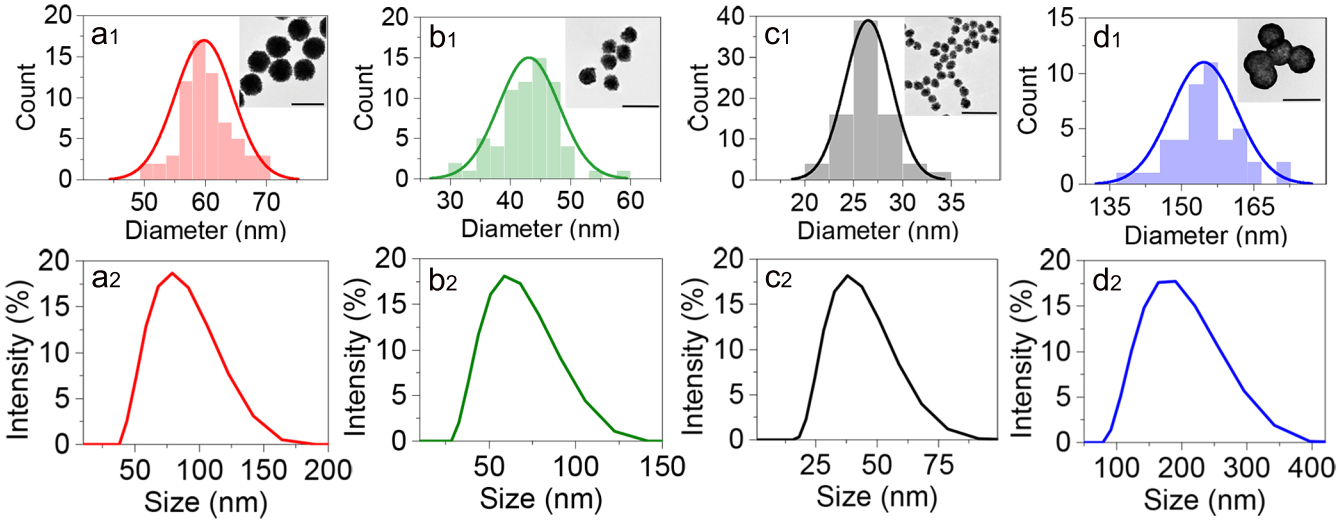
Supporting Table 1: Average diameters for the NPs extracted from the TEM images and DLS distributions as shown in Supporting Figure S1. The values given represent the mean plus/minus one standard deviation for the TEM distributions and the mean plus/minus full width at half maximum (FWHM) for the DLS distributions.

	AuNS nm	Pt70 nm	Pt50 nm	Pt30 nm
Manufacturer stated mean d	150 ± 7	70 ± 4	50 ± 4	30 ± 3
d_{TEM} (mean ± std)	153.6 ± 4.9	59.8 ± 4.8	43.1 ± 5.0	26.5 ± 2.4
d_{DLS} (mean ± FWHM)	170.6 ± 152.5	75.8 ± 64.9	54.7 ± 49.3	31.5 ± 31.3

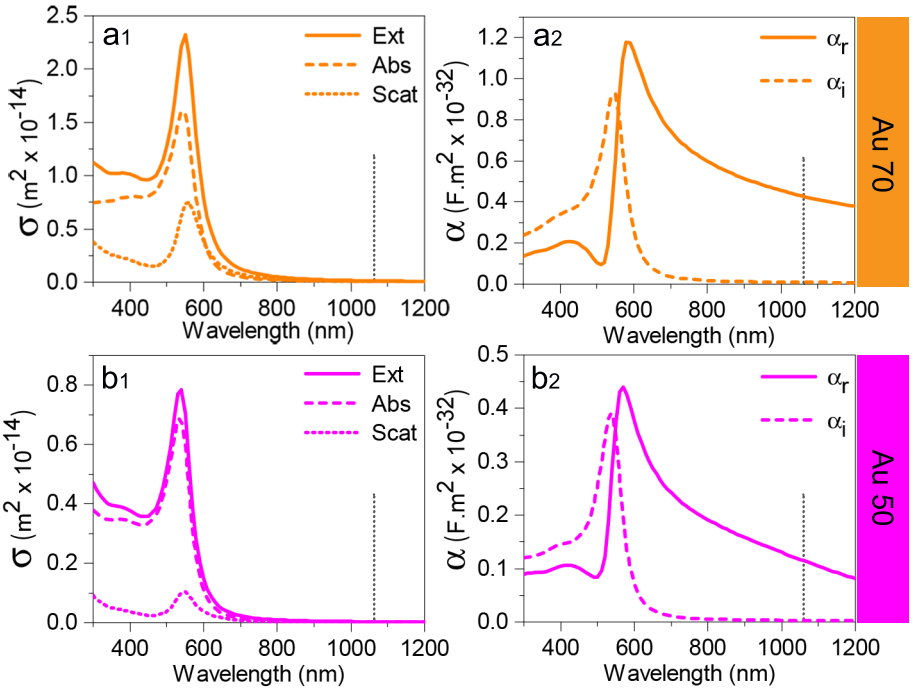
Supporting Table 2: FEM simulated optical cross sections (σ_{abs} and σ_{scat}), polarizabilities ($\alpha = \alpha_r + i\alpha_i$), and experimentally measured trap stiffnesses (κ_y) for absorbing platinum and gold nanoparticles at $\lambda = 1064$ nm using a laser power of 165 mW at the sample. The values given in without parenthesis for κ_y are obtained using an oil immersion objective, the values in parenthesis are obtained using a water immersion objective.

	σ_{abs} $(m^2 \times 10^{-14})$	σ_{scat} $(m^2 \times 10^{-14})$	α_r $(F.m^2 \times 10^{-32})$	α_i $(F.m^2 \times 10^{-32})$	κ_y (pN/nm $\times 10^{-3}$)
Pt70	0.07	0.004	0.39	0.078	3.9 ± 0.6 (4.3 ± 0.6)
Pt50	0.02	0.0003	0.1	0.024	3.8 ± 0.7 (3.6 ± 0.4)
Pt30	0.004	0.000006	0.015	0.004	0.62 ± 0.09
AuNS	0.43	1.6	7.4	0.48	7.2 ± 1.5 (3.3 ± 0.5)
Au70	0.008	0.005	0.43	0.009	(6.3 ± 0.5)
Au50	0.003	0.0003	0.11	0.003	(2.93 ± 0.3)

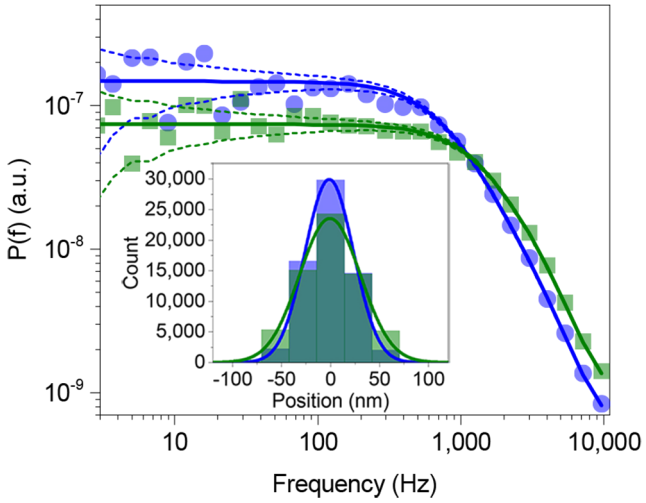
Supporting Figures



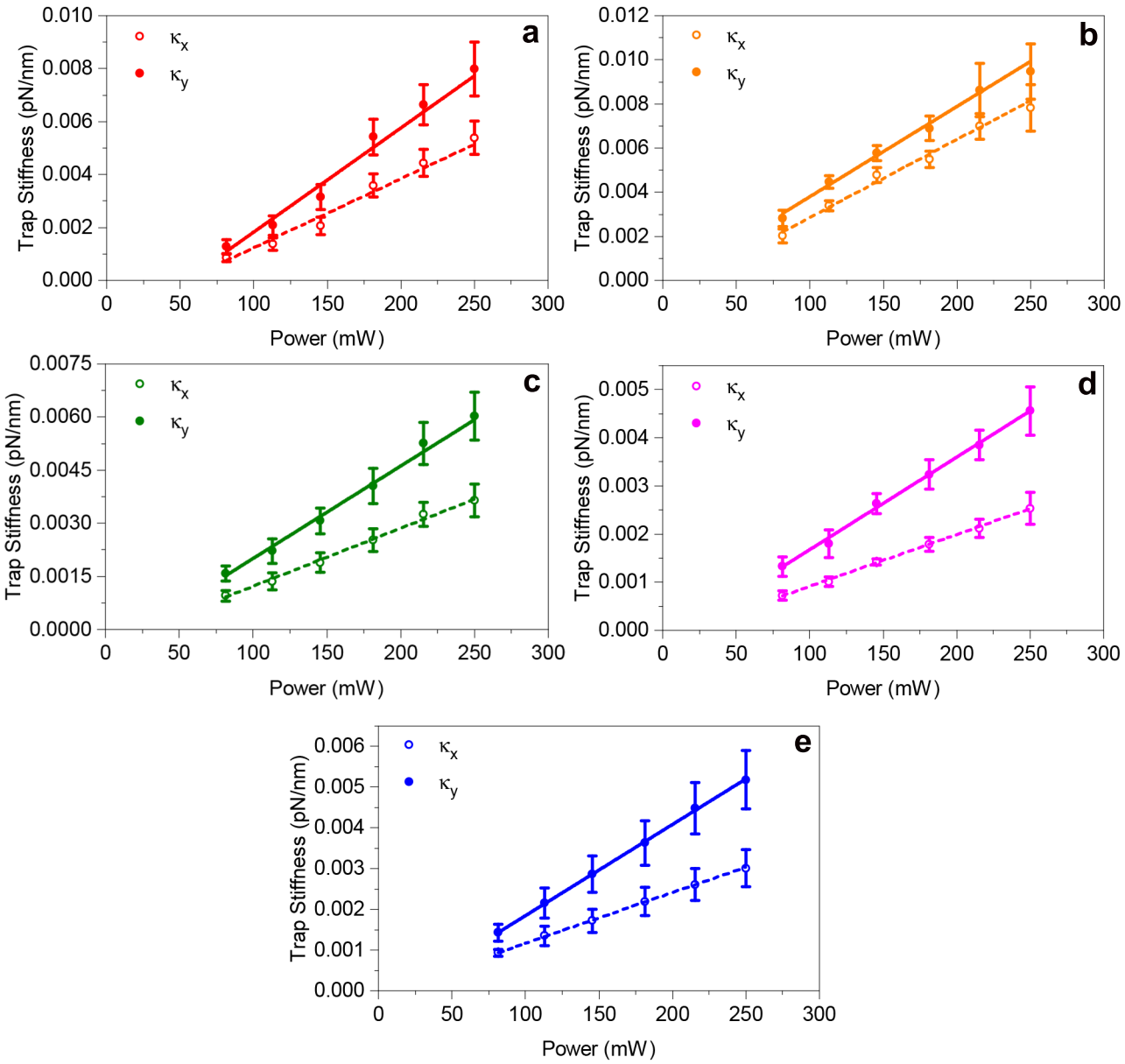
Supporting Figure 1: Size characterization of nanoparticles measured using TEM imaging and DLS measurements. Upper panels a1-d1 represent TEM measured distributions of nanoparticle diameters for Pt70, Pt50 and Pt30, and AuNSs, respectively. Solid lines are a Gaussian fits to the particle's size distribution histograms. A representative TEM micrograph of each sample is shown on the top right corner of each graph. The number of nanoparticles in the distributions are $N_{\mathrm{Pt70}} = 68$, $N_{\mathrm{Pt50}} = 68$ and $N_{\mathrm{Pt30}} = 81$, and $N_{\mathrm{AuNS}} = 32$, respectively. The scale bar on the AuNS TEM image is 200 nm and the scale bar is 100 nm on the other TEM images. The lower panels, a2-d2, show the corresponding particle size distributions obtained from the DLS measurements.



Supporting Figure 2: Optical cross sections and polarizabilities for spherical Au70 (orange) and Au50 (violet). (a1) Absorption, scattering and extinction cross sections of Au70. (a2) Real and imaginary parts of the polarizability for Au70. (b1) Absorption, scattering and extinction cross sections of Au50. (b2) Real and imaginary parts of the polarizability for Au50.



Supporting Figure 3: Power spectra from optical trapping of a Pt50 (green) and a AuNS (blue) using 165 mW at the sample using an oil immersion objective. Full lines show Lorentzian fits yielding corner frequencies of 1440 Hz and 800 Hz, respectively (corresponding to trap stiffnesses of 0.004 pN/nm and 0.0072 pN/nm, respectively). Inset shows the corresponding position histograms, full lines show Gaussian fits.



Supporting Figure 4: Trap stiffnesses for different types of nanoparticles trapped by a water immersion objective (HC PL APO Leica, 63x/NA=1.2), full symbols are in a direction orthogonal to the laser's polarization (κ_y), hollow symbols along the laser's polarization (κ_x). (a) Pt70 (red). (b) Au70 (orange). (c) Pt50 (green). (d) Au50 (violet). (e) 150 nm AuNS (blue). The solid and dashed lines are linear fits and the laser power is at the sample plane. Ten nanoparticles were trapped at each power for each particle type.