RESEARCH HIGHLIGHT

Plasmonic-Upconverting Nanosensors Enable Rapid Optical Detection of Toxic Mercury Ions

RH_PL24; Iona Hill

Mercury Contamination Detection

Mercury exists in three forms: elemental mercury (Hg^0), inorganic mercury (Hg^{2+}), and organic mercury (methyl mercury or other compounds). The highly toxic Hg^{2+} form can be generated during the extraction and handling of elemental mercury, which can subsequently contaminate soil and infiltrate aquifers. This poses a significant health risk, especially in major producing countries like Mexico. Despite its toxicity, mercury production remains high due to its use in applications such as gold extraction and chemical manufacturing.

Rapid, field-based monitoring of mercury contamination is essential, requiring methods that are portable, offer minimal analysis time, and need straightforward sample preparation.

The Sensing Strategy

Researchers from the National Autonomous University of Mexico and the University of Guanajuato have addressed this need by developing a novel luminescent nanosensor for Hg^{2+} detection. This Research Highlight describes their novel strategy for spectral modulation of lanthanide-doped upconversion nanoparticles (UCNPs) *via* plasmonic interactions with gold nanoparticles (AuNPs).

This sensing approach utilises the interaction between the UCNP-AuNP system and Hg^{2+}, which causes the quenching of the green emission. This quenching is enabled by Hg^{2+} altering the AuNP's surface plasmon resonance. The resultant ratiometric luminescence response made the detection of Hg^{2+} sensitive and selective.

Figure 1. Edinburgh Instruments FS5 Spectrofluorometer (left) and RMS1000 Confocal Multimodal Microscope (right).

In this work, researchers characterised their sensors and monitored their colorimetric nanosensor assay using Edinburgh Instrument's FS5 Spectrofluorometer and RMS1000 Confocal Multimodal Microscope (Figure 1). The dual emission-absorption capability of the FS5 was essential for accurate validation.

Materials and Methods

The UCNP-AuNP nanosensors for Hg^{2+} detection were synthesised and then characterised using an FS5 and RMS1000. These instruments were used to measure the samples' absorption, photoluminescence emission, and Raman signatures.

Raman spectra were acquired using a 532 nm laser and a 20x objective. For the colorimetric Hg^{2+} detection assay, the 2-in-1 nature of the FS5 allowed efficient monitoring of the absorption and emission response in one instrument. Its excitation sources included a 150W Xenon arc lamp and a 310 mW continuous-wave 975 nm laser.

Characterisation of UCNP-AuNP Nanosensors

After synthesis, the researchers characterised their UCNP-AuNP nanosensor (Figure 2). The absorbance spectra showed a 520 nm maximum for both free and UCNP-AuNP heterostructure, indicating a stable structure even after interaction between UCNP and AuNP (Figure 2a).

Raman spectroscopy was used to compare the UCNP and UCNP-AuNP. Both showed characteristic lattice vibrations of $NaYF_4$. Furthermore, binding of AuNP to UCNP surface resulted in an increase in Raman signal due to localised surface plasmon resonance of the AuNP (Figure 2b).

When plotted, the plasmon resonance band of the AuNPs overlapped with the UCNP emission spectrum (under 975 nm excitation), particularly with the green emission peaks centred at 520 nm and 540 nm (Figure 2c). These peaks correspond to the Er^{3+} transitions $^2H_{11/2} \rightarrow {}^4I_{15/2}$ and $^4S_{3/2} \rightarrow {}^4I_{15/2}$, respectively. In contrast, the red emission at 655 nm ($^4F_{9/2} \rightarrow {}^4I_{15/2}$ transition) showed minimal spectral overlap with the AuNP absorption band.

Consequently, upon conjugation of the nanoparticles, the UCNP emission intensity decreased, attributed to strong absorption by the AuNPs bound to the UCNP surface. This quenching effect was most pronounced in the green region, coinciding with the highest AuNP absorption. The plasmon-emission interaction was subsequently exploited as a modulation mechanism for emission intensity as a function of Hg^{2+} concentration since any change in the AuNP plasmon resonance was expected to produce a measurable variation in UCNP luminescence.

RESEARCH HIGHLIGHT

Plasmonic-Upconverting Nanosensors Enable Rapid Optical Detection of Toxic Mercury Ions

RH_PL24; Iona Hill

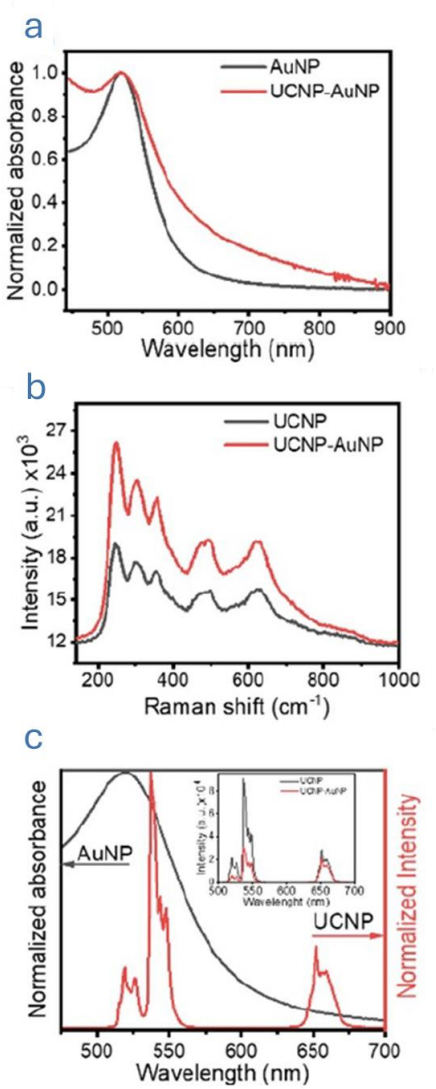

Figure 2. Characterisation of the UCNP-AuNP heterostructures. a) Absorption spectra, b) Raman spectra of the UCNP-AuNP system, c) Superposition of the absorption spectrum of AuNP and the emission spectrum of UCNP (inset: emission changes of UCNP upon association with AuNP in the heterostructures). The image is reprinted from J. M. González *et al.*[1], Copyright (2025), with permission from the Journal of Physics: Photonics.

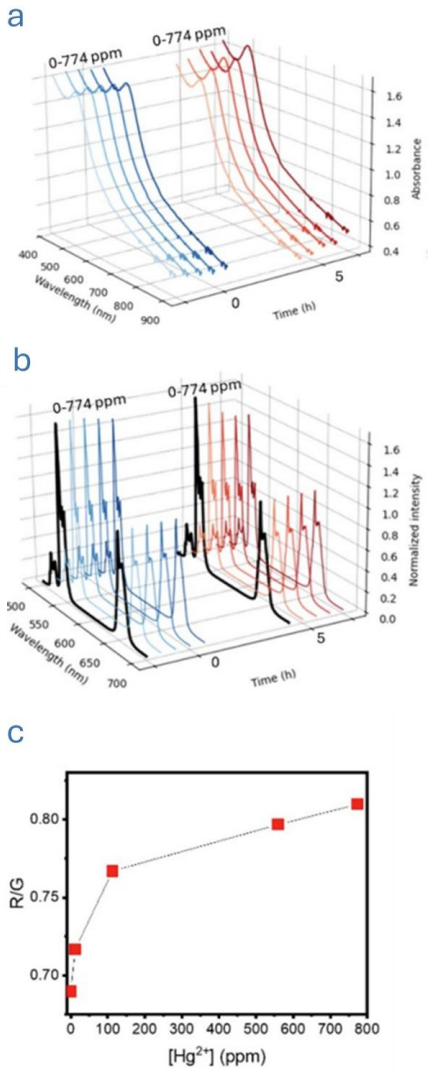

Figure 3. Optical response of the UCNP–AuNP nanosensor at increasing mercury concentrations. a) Absorption spectra after mixing and after 5 hours, b) Emission spectra normalised at 655 nm after mixing and after 5 hours, c) R/G ratio as a function of Hg^{2+} concentration. The image is reprinted from J. M. González *et al.*[1], Copyright (2025), with permission from the Journal of Physics: Photonics.

Detection of Hg^{2+} with UCNP-AuNP

Having established the structural and spectral characteristics of the UCNP–AuNP heterostructure, the team next explored its analytical performance toward mercury detection. The nanosensors were mixed with different concentrations of Hg^{2+} then, absorption and emission spectroscopy measurements were performed (Figure 3).

To allow interaction, the samples were incubated for five hours. After this period, increasing Hg^{2+} concentrations led to two distinct changes (Figure 3a & b): i) an increase in absorption intensity and, ii) a red shift of the wavelength maximum absorption from 520 to 523 nm. The spectral shift was likely due to morphological modification of the AuNP resulting from deposition of elemental (Hg^0) on the surface. The increase in absorbance intensity enhanced the spectral overlap with the $^4S_{3/2} > {}^4I_{15/2}$ transitions, leading to a noticeable decrease in green band emission.

A luminescence calibration curve was created by plotting the red/green (R/G) ratio against the Hg^{2+} concentration. The curve

Plasmonic-Upconverting Nanosensors Enable Rapid Optical Detection of Toxic Mercury Ions

RH_PL24; Iona Hill

demonstrated a progressive increase in the R/G ratio followed by saturation. This saturation occurred at relatively low concentrations of Hg^{2+}, which limited the working range of the detection assay.

Improving Speed and Precision of Hg^{2+} Detection

It was clear that the interaction between Hg^{2+} and UCNP-AuNP needed mediation to prevent saturation. The researchers therefore investigated the effect of incorporating diethylenetriamine (DETA) to enhance the interaction between AuNP and Hg^{2+} sensing process.

One hour after mixing, a prominent enhancement in absorption intensity and reduction in green emission with increasing concentrations of Hg^{2+} was observed (Figure 4a & b). This led to large variations in the R/G ratio reaching an increase of approximately 25% compared to initial measurements (Figure 4c).

By linear fitting the R/G ratio in the region of low Hg^{2+} concentrations, the limit of detection was calculated to be 0.25 ppm. The addition of DETA not only improved analytical speed but also expanded the working range of the assay, demonstrating its suitability for near-real-time monitoring.

Conclusion

This work demonstrated the potential of the UCNP-AuNP/DETA system as a versatile platform for portable, user-friendly Hg^{2+} detection, and shows how dual-mode spectroscopy can accelerate field-deployable toxic metal sensing.

The FS5 and RMS1000 were both used for characterisation of these nanomaterials and for detecting emission changes related to sensing Hg^{2+}. The 2-in-1 FS5 spectrometer allowed measurement of both absorption and fluorescence spectra in a single instrument. Overall, this work demonstrates how advanced spectroscopic tools, such as the FS5 and RMS1000, empower researchers to translate nanoscale phenomena into practical sensing technologies.

Full Publication

The results in this Research Highlight were published in *Journal of Physics: Photonics*. The full article can be found here: https://doi.org/10.1088/2515-7647/ae0121

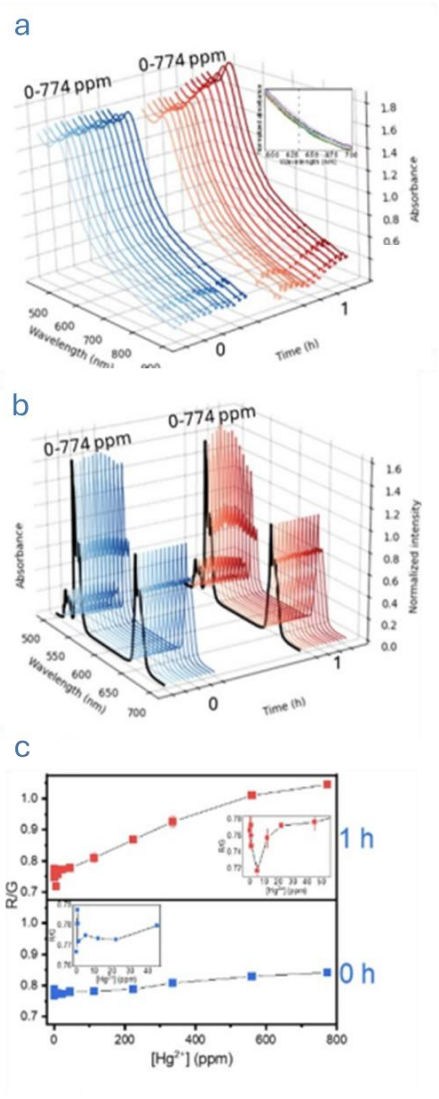

Figure 4. Response of UCNP-AuNP/DETA system in presence of Hg^{2+}. a) Absorption spectra at 0 h and 1 h, b) emission spectra, c) R/G ratio at 0 and 1 h interaction. The image is reprinted from J. M. González *et al.*[1], Copyright (2025), with permission from the Journal of Physics: Photonics.

References

1. J. M. González *et al,* Plasmonic-upconverting nanosensor for automated colorimetric and ratiometric sensing of Hg^{2+} via digital readout and neural networks, 2025 *J. Phys. Photonics* **7** 045012

For more information, please contact:

+44 (0) 1506 425 300
sales@edinst.com
www.edinst.com