Supplementary Information

Selective colorimetric NO (g) detection with modified gold nanoparticles using click chemistry

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General procedures:

All reagents were commercially available, and were used without purification. Silica gel 60 F254 (Merck) plates were used for TLC. Milli-Q ultrapure water was used for the synthesis of AuNPs and the sensing experiments. NO (g), NO_2 (g) and CO (g) were obtained from commercially available gas cylinders. SO_2 (g) and CO_2 (g) were generated in situ following standard protocols. ^{1}H-NMR and ^{13}C-NMR spectra were recorded on a Bruker 300 MHz spectrometer. Chemical shifts are reported in ppm with tetramethylsilane as an internal standard. High resolution mass spectra were recorded in the positive ion mode on a VG-AutoSpec mass spectrometer. UV-vis absorption spectra were recorded using a 1 cm path length quartz cuvette on a Shimadzu UV-2101PC spectrophotometer. All measurements were carried out at 293 K (thermostated). Z-potential values were measured in a Malvern Zetasizer ZS, for 3 times in 10-25 cycles. The TEM electronic images were made on a JEOL-1010 transmision electron microscope operating at 100 KV.

Synthesis of 2-azidoethyl 5-(1,2-dithiolan-3-yl)pentanoate (1)

A 100 mL round-bottom flask was charged with (±)-α-lipoic acid (1.5 g, 7.27 mmol), DCC (1.5 g, 7.27 mmol), and anhydrous CH_2Cl_2 (20 mL). The reaction mixture was cooled to 0^{o}C in an ice-water bath and a solution of 2-bromoethanol (0.5 mL, 6.9 mmol) and a catalytic amount of DMAP in anhydrous CH_2Cl_2 (20 mL) was added dropwise over a period of 1 h under magnetic stirring. After the addition was completed, the reaction mixture was stirred at 0^{o}C for 2 h and then allowed to warm to room temperature for 24 h. After removing the insoluble salts by filtration, the filtrate was concentrated and further purified by silica gel column chromatography using hexane/ethyl acetate (4:6, v/v) as eluent. 2-Bromoethyl 5-(1,2-dithiolan-3-yl)pentanoate was obtained as a yellow oil (1.36 g, 60% yield).

^{1}H NMR (300 MHz, $CDCl_3$): δ= 4.39 (t, *J*= 6.2 Hz, 2H), 3.60-3.50 (m, 1H), 3.51 (t, *J*= 6.2 Hz, 2H), 3.25-3.10 (m, 2H), 2.52-2.42 (m, 1H), 2.37 (t, *J*= 7.3 Hz, 2H), 1.96-1.86 (m, 1H), 1.75-1.63 (m, 4H), 1.55-1.45 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$) δ= 173.1, 63.8, 56.5, 40.4, 38.6, 34.7, 34.0, 29.0, 28.9, 24.8.

HRMS (ESI): *m/z* calcd. for $C_{10}H_{18}BrO_2S_2$ ($[M+H]^+$), 314.993 (100%) and 312.993 (93%); found 314.990 and 312.992.

2-Bromoethyl 5-(1,2-dithiolan-3-yl)pentanoate (2.0 g, 6.4 mmol) and sodium azide (1.25 g, 19.2 mmol) were dissolved in DMF (10 mL) and stirred at 60 ^{o}C for 48 h. The reaction mixture was diluted with dichloromethane, washed with water and $NaHCO_3$ (aq), dried over anhydrous $MgSO_4$ and concentrated to obtain 2-azidoethyl 5-(1,2-dithiolan-3-yl)pentanoate (**1**) as a light yellow liquid (1.38 g, 78%).

^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm)= 4.25 (t, *J*= 5.1 Hz, 2H), 3.57 (qt, J = 6.6 Hz, 1H), 3.48 (t, J = 5.1 Hz, 2H), 3.25–3.07 (m, 2H), 2.54–2.42 (m, 1H), 2.38 (t, *J*= 7.4 Hz, 2H), 1.97–1.85 (m, 1H), 1.75–1.63 (m, 4H), 1.54–1.44 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm)= 173.2, 63.0, 56.4, 49.9, 40.4, 38.6, 34.7, 34.0, 28.8, 24.7.

HRMS (ESI): *m/z* calcd. for $C_{10}H_{18}N_3O_2S_2$ ($[M+H]^+$): 276.084; found 276.082.

Synthesis of but-3-yn-1-yl 5-(1,2-dithiolan-3-yl)pentanoate (2)

A 100 mL round-bottom flask was charged with lipoic acid (1.5 g, 7.27 mmol), DCC (1.5 g, 7.27 mmol), and anhydrous CH_2Cl_2 (20 mL). The reaction mixture was cooled to 0^{o}C and a solution of 3-butyn-1-ol (0.53 mL, 6.9 mmol) and DMAP (cat. amount) in anhydrous CH_2Cl_2 (20 mL) was added dropwise over a period of 1 h under magnetic stirring. After the addition was completed, the reaction mixture was stirred at 0 ^{o}C for 2 h and then allowed to warm to room temperature for 24 h. After removing the insoluble salts by filtration, the filtrate was concentrated and the residue was purified by silica gel column chromatography using hexane/ethyl acetate (4:6, v/v) as eluent. Compound **2** was obtained as yellow oil (1.02 g, 45% yield).

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm)= 4.18 (t, *J*= 6.7 Hz, 2H), 3. 56 (qt, *J*= 6.6 Hz, 1H), 3.22–3.07 (m, 2H), 2.53–2.41 (m, 3H), 2.35 (t, *J*= 7.4 Hz, 2H), 2.00 (t, *J*= 2.5 Hz, 1H), 1.96–1.85 (m, 1H), 1.76–1.59 (m, 4H), 1.53–1.43 (m, 2H).

^{13}C NMR (75 MHz, $CDCl_3$) δ (ppm)= 173.3, 80.2, 70.0, 62.1, 56.5, 40.4, 38.6, 34.7, 34.1, 28.9, 24.8, 19.2.

HRMS (ESI): *m/z* calcd. for $C_{12}H_{19}O_2S_2$ ($[M+H]^+$), 259.0826; found, 259.0810.

Preparation of the functionalized AuNPs.

All glassware was thoroughly cleaned with freshly prepared aqua regia (HCl: HNO_3, 3:1), rinsed thoroughly with deionized water and dried in air. AuNPs with a diameter of ca. 13 nm were synthesized as reported previously.[1] Briefly, 10 mL of aqueous 38.8 mM trisodium citrate solution was added to an aqueous boiling solution of $HAuCl_4$ (100 mL, 1 mM) and the resulting solution was kept continuously boiling for 30 min until a red solution was obtained. The solution was cooled to room temperature and was then stored in a refrigerator at 4^{o}C for use. Modification of AuNPs through the ligand-exchange reaction was performed at room temperature as follows: 20 µl of 0.01 M NaOH aqueous were added to the 10 mL of the as-prepared citrate capped AuNPs. Then, 200 µl of LA ($1\cdot10^{-3}$ M in methanol) and the corresponding amount of compounds **1** or **2** (10^{-3} M in methanol) were added simultaneously and the solution was stirred overnight. To purify the AuNPs, the mixture were centrifuged for 20 min at 14000 rpm and supernatants were decanted; then the resulting AuNPs were resuspended in water. The whole process was repeated twice. The AuNPs were characterized by UV-vis spectroscopy, TEM and zeta-potential measurements.

Zeta-potential values (mV) for the AuNPs suspended in deionized water: **AuNP1**, -45.4; **AuNP2**, -38.9.

Ascorbic acid and NO titration studies

The ascorbic acid titration studies were carried out as follows: The initial aqueous mixture (750 µL) containing **AuNP1** and **AuNP2** ($4\cdot10^{-10}$ M) and $Cu(OAc)_2$ (40 µM) was prepared by adding 10 µL of $Cu(OAc)_2$ (3 mM) to a solution containing equimolecular amounts of **AuNP1** and **AuNP2** in deionized water. The UV-vis spectrum was registered. Then increasing amounts of sodium ascorbate (3mM in water, 1 µL aliquots) were added, and the UV-spectra were recorded. The total sodium ascorbate concentration during the titration varied from 3 µM to 36 µM.

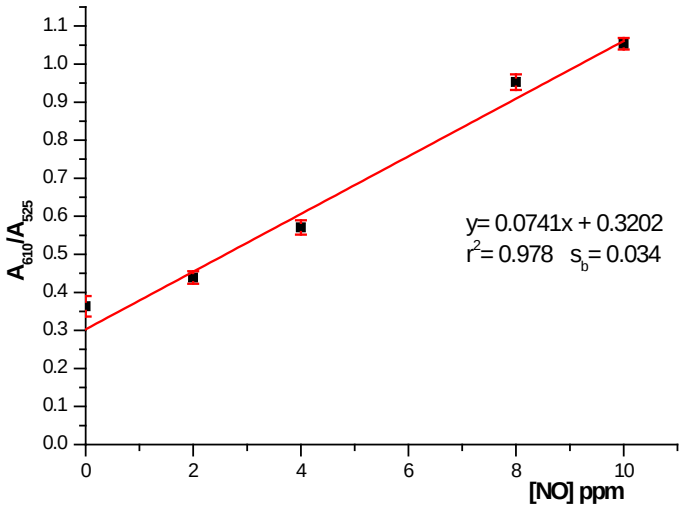
The NO titration studies were carried out as follows: A mixture of 750 µL of **AuNP1** ($5.3\cdot10^{-9}$ M in water) and 750 µL of **AuNP2** ($5.3\cdot10^{-9}$ M in water) at pH 7.8 was diluted to 12 mL with methanol (final AuNPs concentration of $3.3\cdot10^{-10}$ M). 1mL of the previously prepared water/methanol solution was placed in a vial and 10 µL of aqueous $Cu(OAc)_2$ (3 mM) were added. The vial was introduced inside a 250 mL round bottom flask filled with a N_2 atmosphere containing NO (g) (2 ppm) for 5 min. Then the vial was taken out of the flask and let stand in the air for 5 more minutes and the UV-vis spectrum was immediately

registered (from 400 to 800 nm with a scan rate of 0.125 nm/seg). The same procedure was repeated with different NO concentrations.

Calculation of LOD

The limit of detection for NO (g) was obtained from the plot of the ratio of the absorbance intensities at 525 and 610 nm (A_{610}/A_{525}) versus NO concentration (in ppm). LOD was calculated by using the equation (1), where K=3; S_b is the standard deviation of the blank and m is the slope of the calibration curve.

$$\mathrm{LOD} = \mathrm{K} \cdot \frac{S_b}{m} \quad (1)$$



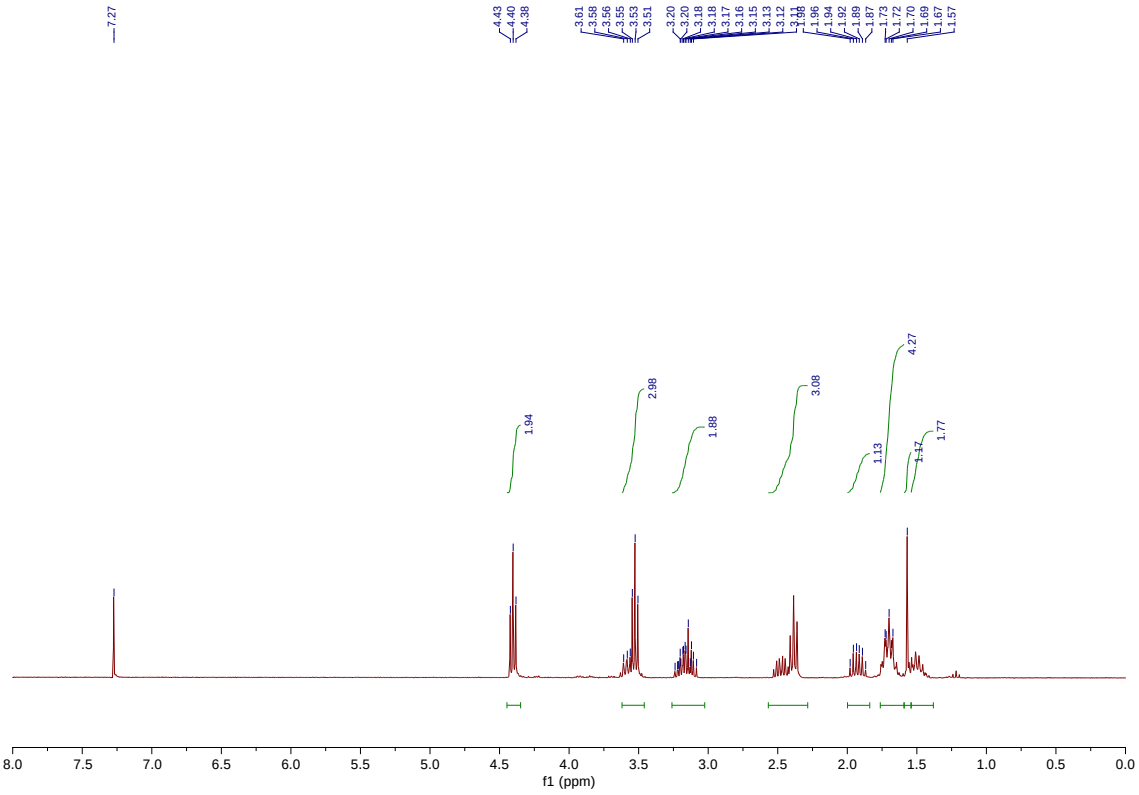
Interference Studies

The same experimental procedure previously described for NO detection was followed for the interference studies. In this case 1 mL H_2O/MeOH solutions (1:7 v/v) containing the AuNPs and Cu(II) were exposed for 5 min to a nitrogen atmosphere containing 50 ppm of the different interferents. The solutions were allowed to stand for 5 min in the air and the corresponding UV-vis spectra were recorded. Finally the solution of the AuNPs and Cu(II) was exposed a nitrogen atmosphere containing 50 ppm of the interferents and 50 ppm of NO, in the same conditions than above, and the UV-vis spectra was registered. In the absence of NO, no color changes were observed and the UV-vis spectra were almost

identical to that of the original NPs. However in the presence of the interferents plus NO a clear change in the color of the solution was observed (Figure S7) with the corresponding red shift in the UV-spectrum indicative of the aggregation process.

NO, NO_2 and CO where obtained from commercially available gas cylinders. SO_2 (g) was generated from a mixture of granulated copper and 96 % H_2SO_4; CO_2 (g) was generated from a mixture sodium carbonate and concentrated hydrochloric acid.

Figure S1. ^{1}H NMR and ^{13}C NMR spectra of 2-bromoethyl 5-(1,2-dithiolan-3-yl)pentanoate in $CDCl_3$ at 300 and 75 MHz



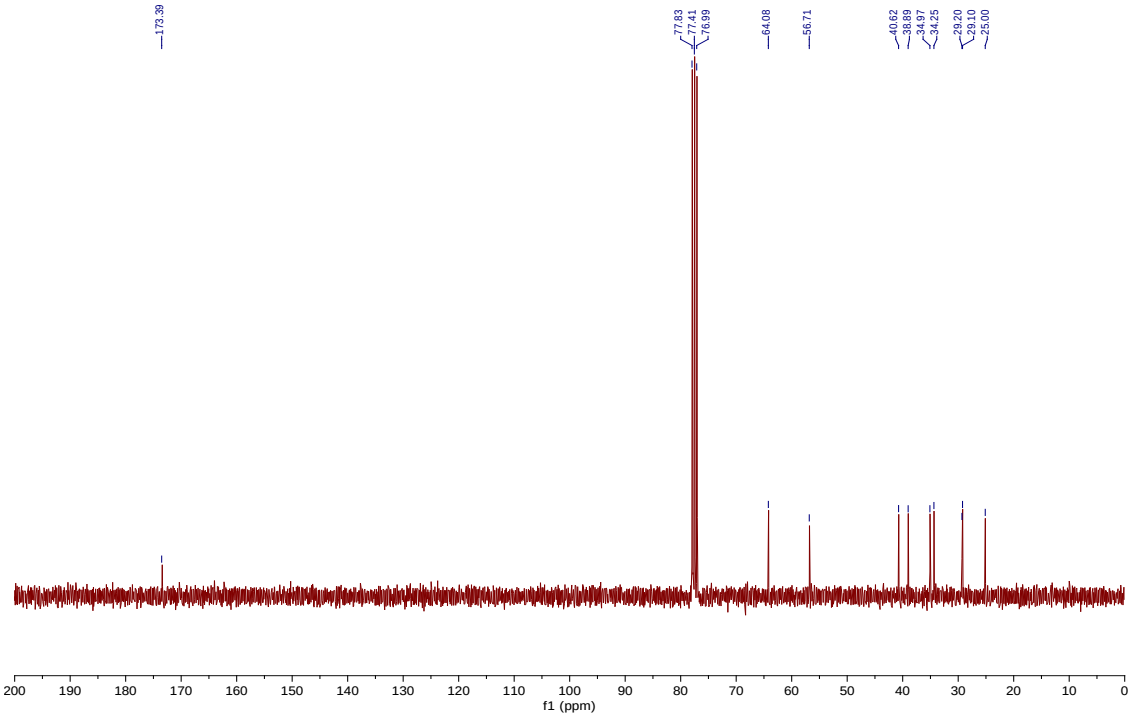
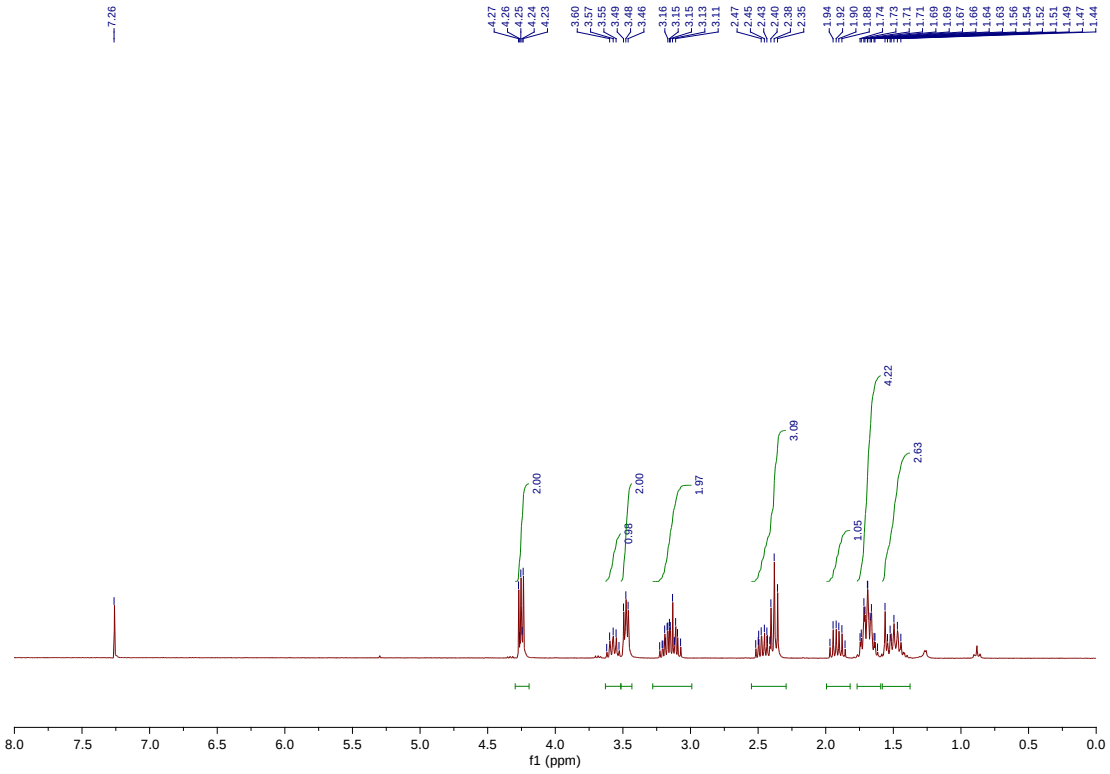


Figure S2. ^{1}H NMR and ^{13}C NMR spectra of azide derivative **1** in $CDCl_3$ at 300 and 75 MHz



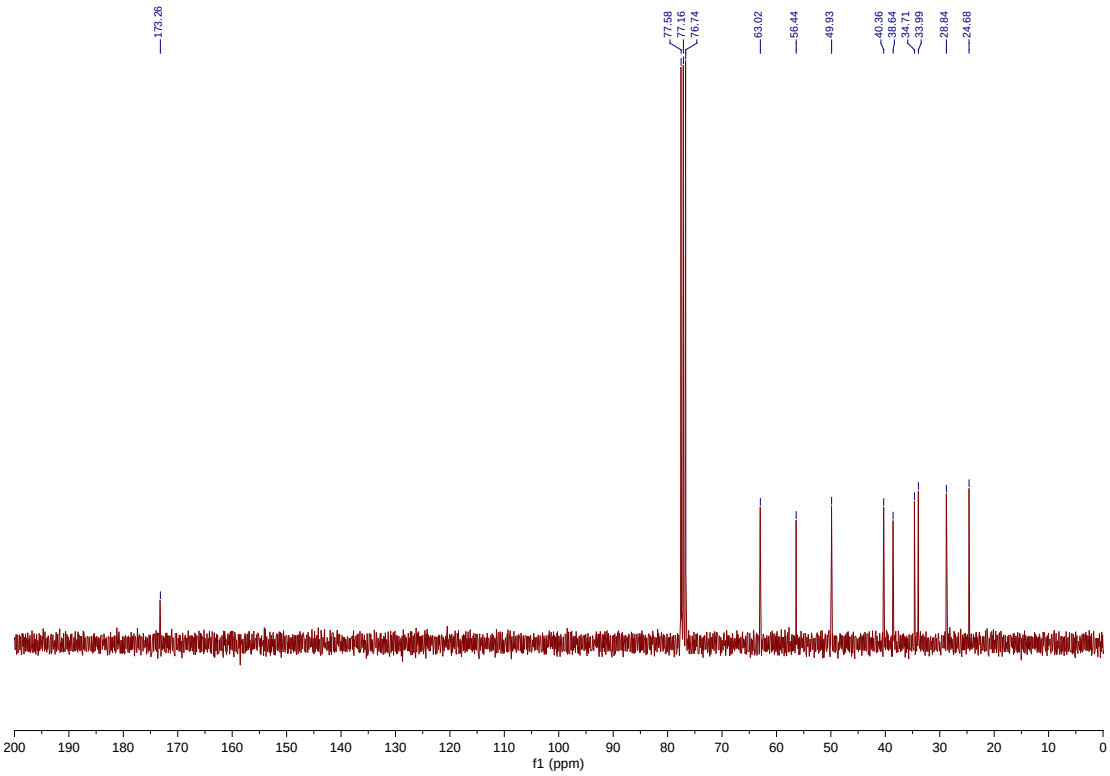
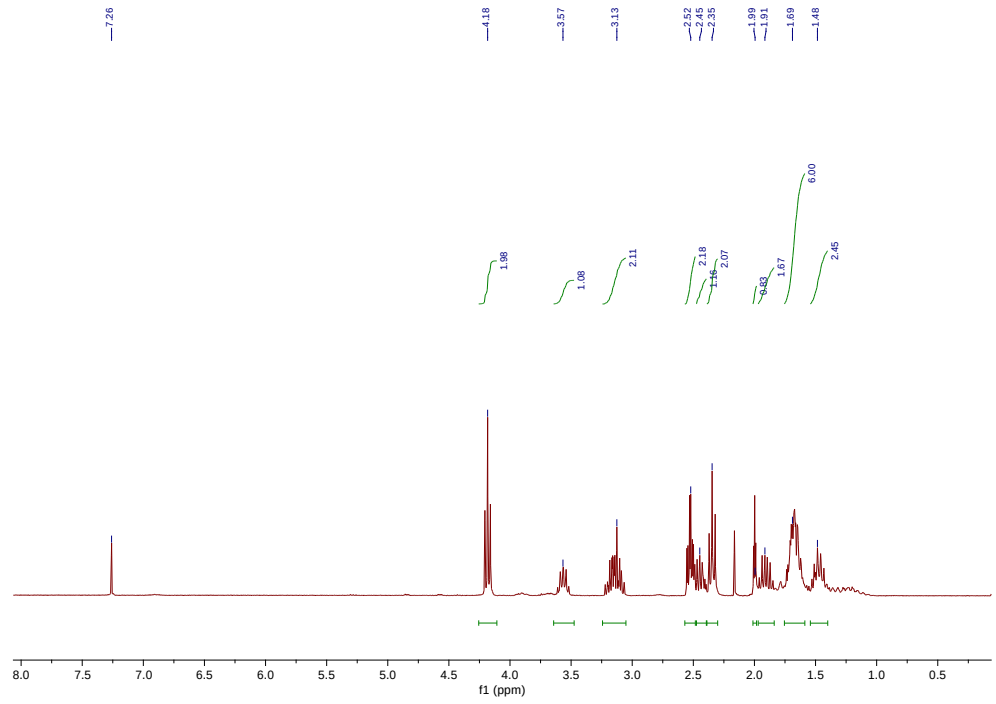


Figure S3. ^{1}H NMR and ^{13}C NMR spectra of compound **2** in $CDCl_3$ at 300 and 75 MHz



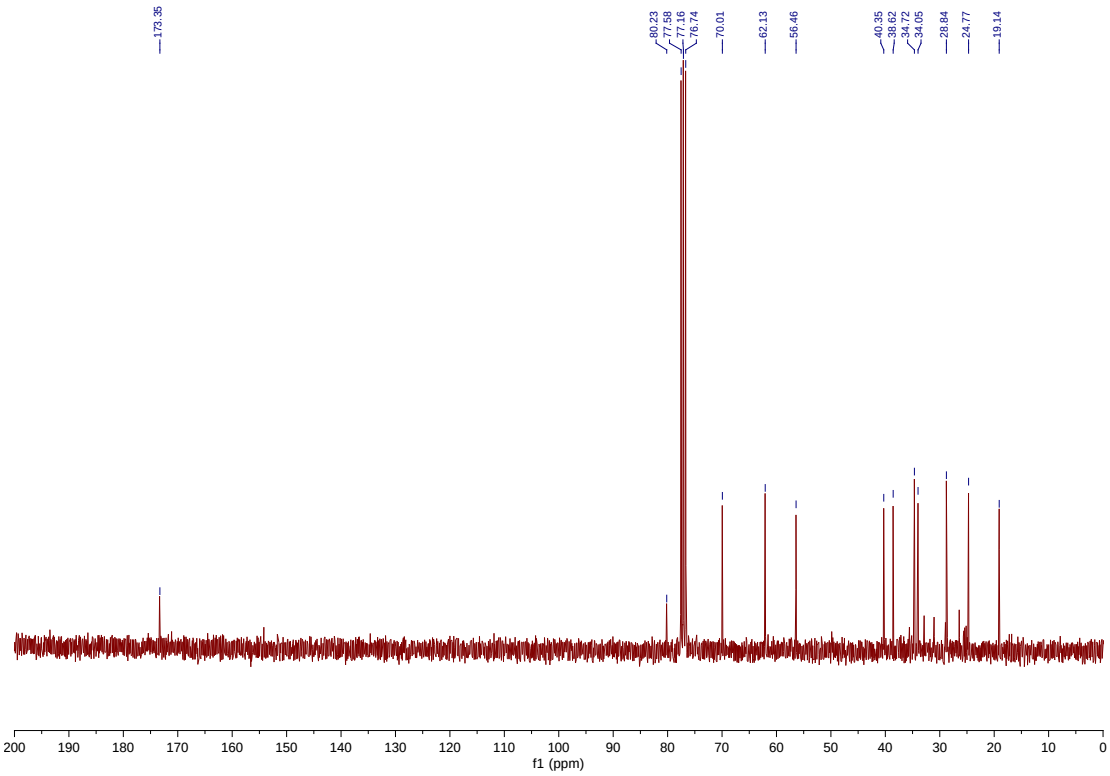


Figure S4. UV-vis spectra of the titration of a mixture of **AuNP1**, **AuNP2** and $Cu(OAc)_2$ ($4 \cdot 10^{-5}$ M) in water upon addition of increasing amounts of sodium ascorbate ($4 \cdot 10^{-6}$M to $4 \cdot 10^{-4}$ M)

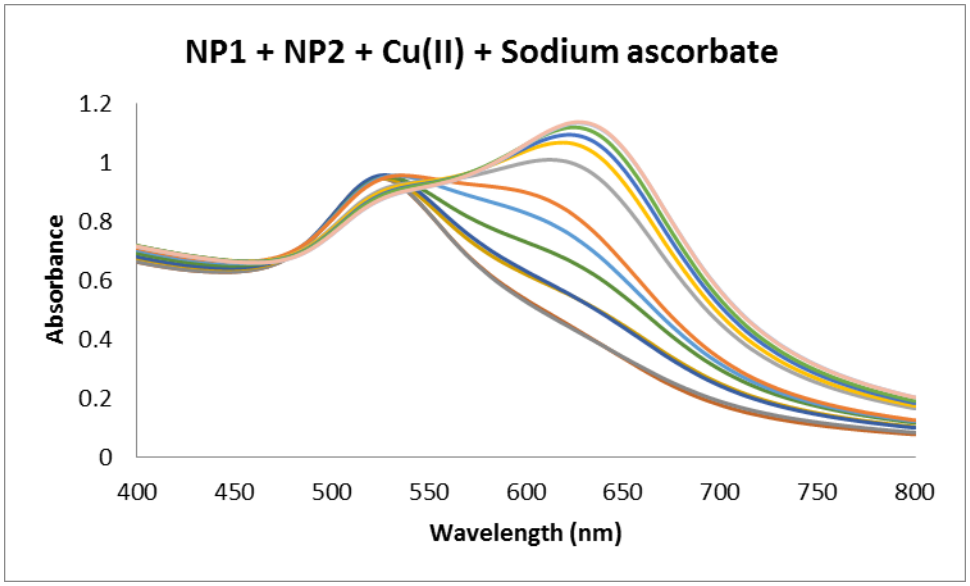


Figure S5. TEM images of an equimolecular mixture of **AuNP1** and **AuNP2** (left); and aggregated AuNPs upon addition of excess of sodium ascorbate in presence of copper acetate, at 200 nm resolution.

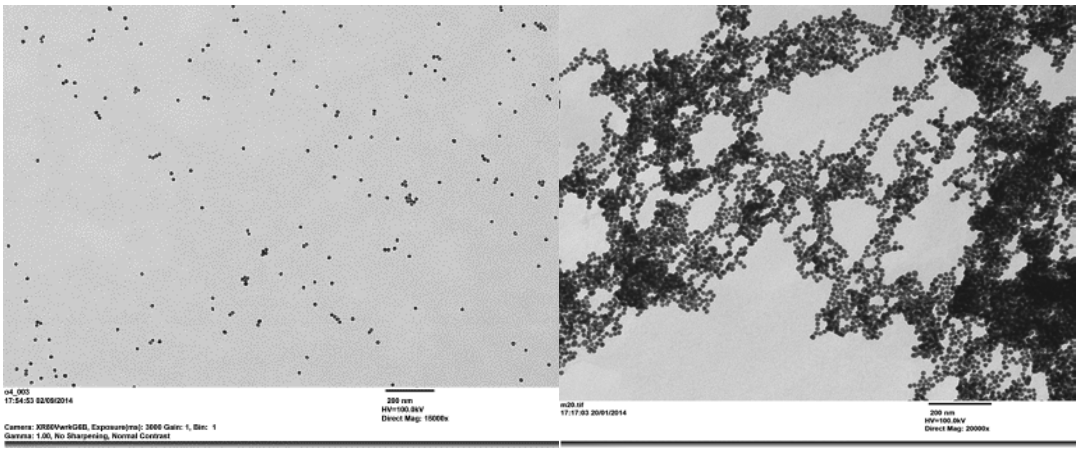
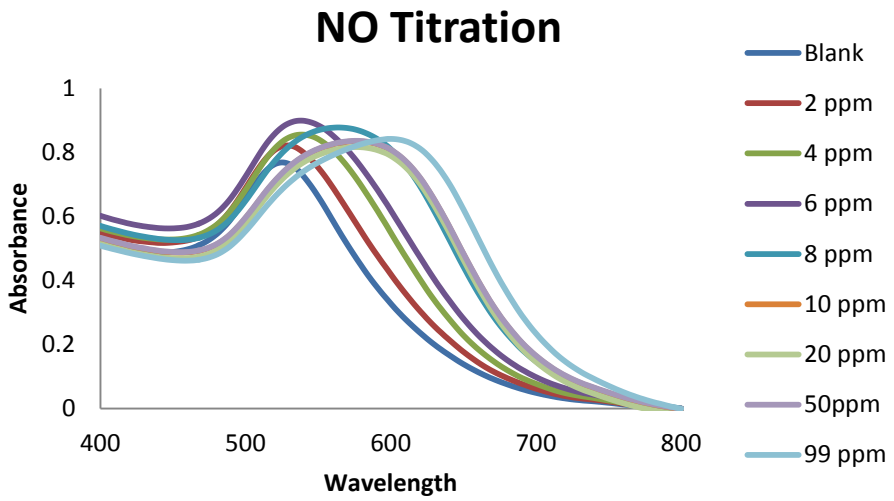


Figure S6 Up: UV-vis spectra of titration of a mixture of **AuNP1**, **AuNP2** and Cu(AcO)2 in MeOH:H2O (7:1), upon exposition to increasing amounts of NO (g). Bottom: Plot of A610/A525 vs NO concentration (in ppm)



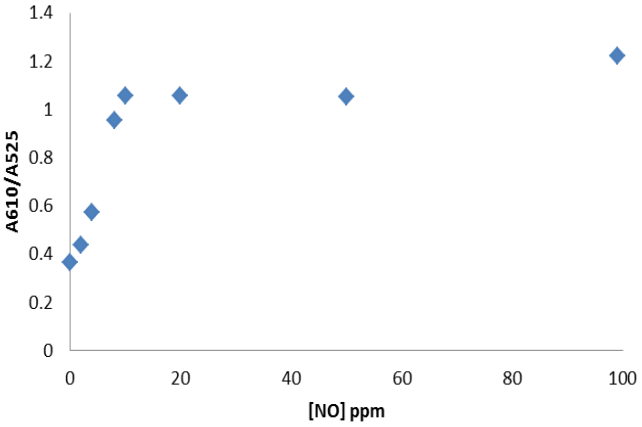


Figure S7. TEM images of an equimolecular mixture of **AuNP1**, **AuNP2** and Cu(II), in the absence (up left), and in the presence of 6 ppm of NO (g) (up right) and 99 ppm of NO (g) (bottom).

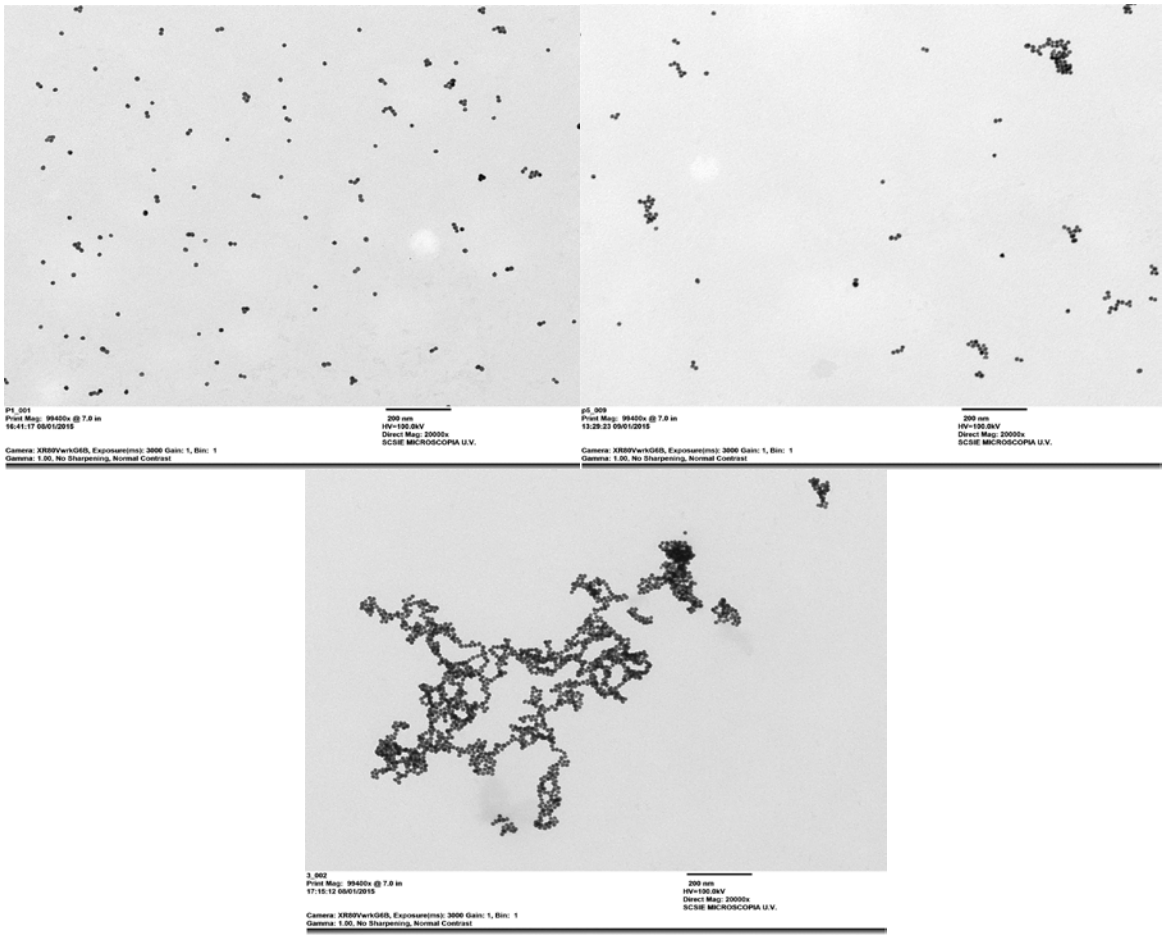
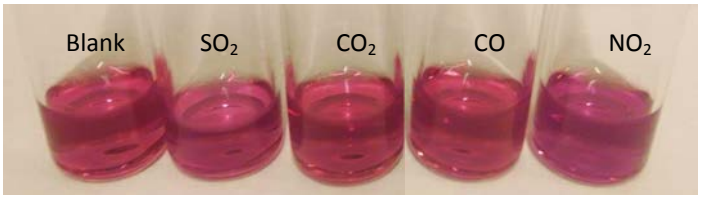
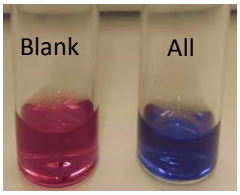


Figure S8. Photograph of solutions of **AuNP1**, **AuNP2** and Cu(II) in MeOH:H2O (7:1) after exposure to the different interferents (SO_2, CO_2, CO and NO_2, 50 ppm each) (left); photograph of the blank solution and the same solution after exposure to a mixture of SO_2, NO_2, CO_2 and NO (right)





References

[1] A. Martí, A. M. Costero, P. Gaviña, S. Gil, M. Parra, M. Brotons-Gisbert, J. F. Sánchez-Royo, *Eur. J. Org. Chem.* **2013**, 4770-4779.