Experimental Section

Chemicals

$RuCl_3 \cdot xH_2O$ (Sterm), 1,2-propanediol (ACS reagent, Aldrich), sodium acetate (Aldrich), 8-mercaptooctanoic acid (Aldrich), 11-mercaptoundecanoic acid (Aldrich), 2-(2-methoxyethoxy)ethanethiol (Aldrich), 1-octanethiol (Aldrich), and *tert*-butyl nitrite (Aldrich) were purchased from commercial source and were used as received. All reagents were of analytic reagent grade. Water was supplied by a Barnstead Nanopure water system (18.2 MΩ).

Instrumentation

Infrared spectra, in the region 4000 – 600 cm^{-1} were recorded on a Nicolet Nexus 670 FTIR infrared spectrophotometer with 4 cm^{-1} resolution. Analyses were performed on solid samples that were deposited on a KBr window by evaporation of several drops of a hexane solution. ^{1}H and ^{13}C NMR spectra were recorded on Bruker DPX-300 or Avance400 FT-NMR spectrometers with chemical shifts (in ppm) relative to tetramethylsilane. C, H, N and S analysis of all ruthenium nanoparticles were performed by MEDAC Ltd, UK or Elementar Vario EL Analyzer housed at City University of Hong Kong. Ru content was analyzed by ICP-MS (Agilent 7500a). Gas Chromatographic analyses were performed on a Agilent 6890N gas chromatograph with HP-5 column (30 m × 0.25 mm × 0.25 μm) and flame ionization detector. GC-MS measurements were carried out on an Agilent 6890N gas chromatograph interfaced to an Agilent 5973 mass selective spectrometer. XPS analysis was performed on a Physical Electronics Model 5600 with monochromatic Al Kα as X-ray source housed at the Hong Kong University of Science and Technology. Transmission electron miscopy (TEM) imaging was performed using Philips Tecnai G2 20 S-TWIN equipped with an energy-dispersive spectrometer (EDS) micro-analysis system. The sizes of ruthenium nanoparticles were determined by image analysis of at least 200 particles at 5 randomly selected sites.

Synthesis

RuNP1. Ruthenium metal nanoparticles of size about 2 nm in diameter were prepared by reduction of $RuCl_3 \cdot xH_2O$ in 1,2-propanediol.[1] In a typical experiment, 130 mg (0.5 mmol) of

$RuCl_3 \cdot xH_2O$ was added to 200 mL 1,2-propanediol containing 320 mg (4 mmol) of NaOAc at 150 °C under stirring, and the solution mixture was heated for further 10 min. After cooling the solution to room temperature, 2.5 mmol of 1-octanethiol in 100 mL of toluene was added and was allowed to stir overnight. Crude product was obtained after removal of toluene. **RuNP1** was purified by removal of alkyl thiol with methanol and acetone. Yield: 140 mg. ^1H NMR (400 MHz, $CDCl_3$): δ = 0.89 (br s), 1.30 ppm (br s). ^{13}C NMR (75.48 MHz, $CDCl_3$): δ = 14.14, 22.79, 29.68, 32.04 ppm (Figure S1). The average of three element analysis of **RuNP1** gave 39.63 % C, 6.88 % H, 12.70 % S, < 0.1 % N, 39.7 % Ru (First: 39.15 % C, 6.84 % H, 12.59 % S, < 0.1 % N, and 40.5 % Ru; Second: 40.22 % C, 6.89 % H, 12.57 % S, < 0.1 % N, 39.5 % Ru; Third preparation, 39.52 % C, 6.90 % H, 12.93 % S, < 0.1 % N, 39.2 % Ru), with corresponding S/Ru molar ratio of 1 : 1 in the nanoparticles. The C/H and C/S ratios are those of 1-octanethiolate. We have observed two trivial IR absorption peaks in the 2050-1950 cm^{-1} region (Figure S2a). A small peak at 2010 cm^{-1} was assigned to the stretching vibration of CO linearly absorbed on the Ru surface. Low-frequency bands at 1996 and 1965 cm^{-1} were assigned to bridging CO.

RuNP1-NO. In a typical experiment, ^tBuONO (0.15 mmol) was added to **RuNP1** (100 mg, ~ 40 mg of Ru) in toluene (100 mL), and was allowed to stir overnight in dark. An aliquot of solution was drawn from the reaction mixture, and organic products were determined by GC or GC-MS. Unreacted ^tBuONO and solvent were removed by vacuum. **RuNP1-NO** was obtained by excessive washing with hexane and Et_2O. Yield: 80 mg. ^1H NMR (400 MHz, $CDCl_3$): δ = 0.88 (br s), 1.28 ppm (br s). ^{13}C NMR (75.48 MHz, $CDCl_3$): δ = 14.11, 22.68, 29.23, 31.83 ppm (Figure S1). Elemental analysis gave 32.20 % C, 5.82 % H, 11.90 % S, 1.33 % N and 47.4 % Ru, with corresponding to S/Ru molar ratio of 0.79 and N/Ru molar ratio of 0.20. The C/H and C/S ratios are those of 1-octanethiolate. *Reaction of ^tBuONO (0.375 mmol) with **RuNP1** (*100 mg). Elemental analysis gave 29.67 % C, 5.54 % H, 12.05 % S, 1.60 % N, and 49.5 % Ru, with corresponding to S/Ru molar ratio of 0.77 and N/Ru molar ratio of 0.23. *Reaction of tBuONO (0.75 mmol) with **RuNP1** (100 mg)*. Elemental analysis gave 32.20 % C, 5.69 % H, 12.29 % S, 2.07 % N and 45.6 % Ru, with corresponding to S/Ru molar ratio of 0.84 : 1 and N/Ru molar ratio of 0.25:1.

RuNP1-CO. **RuNP1** (100 mg) were dissolved and bubbled with CO for 0.5 h. The black solids were obtained after removal of toluene under vacuum and showed adsorption peaks at

1933 and 2023 cm^{-1}, tentatively assigned to Ru-CO stretching. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.89 (br s), 1.30 ppm (br s). ^{13}C NMR (75.48 MHz, $CDCl_3$): δ = 14.04, 22.68, 29.47, 31.91 ppm. Elemental analysis gave 39.43 % C, 6.84 % H, 12.85 % S, < 0.1 % N and 41 % Ru with the corresponding S/Ru molar ratio of 1.01:1.

RuNP2-NO. The preparation is similar to **RuNP1**, except that 2-(2-methoxyethoxy)ethanethiol dissolved in 50 mL CH_2Cl_2 was used. **RuNP2** was obtained by extraction with CH_2Cl_2 and washed with water to remove excess 1,2-propanediol. ^{t}BuONO (0.15 mmol) was added to **RuNP2** (40 mg) in CH_2Cl_2 (50 mL), and was allowed to stir overnight in dark. Unreacted ^{t}BuONO and solvent were removed by vacuum. **RuNP2-NO** was obtained by excessive washing with hexane/Et_2O mixture. Yield: 30 mg. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.38 (br s), 3.57 ppm (br s). Elemental analysis gave 21.55 % C, 4.32 % H, 12.45 % S, 1.20 % N and 45.0 % Ru with the corresponding S/Ru and N/Ru molar ratios of 0.87 and 0.19 respectively. IR: 1866 cm^{-1}.

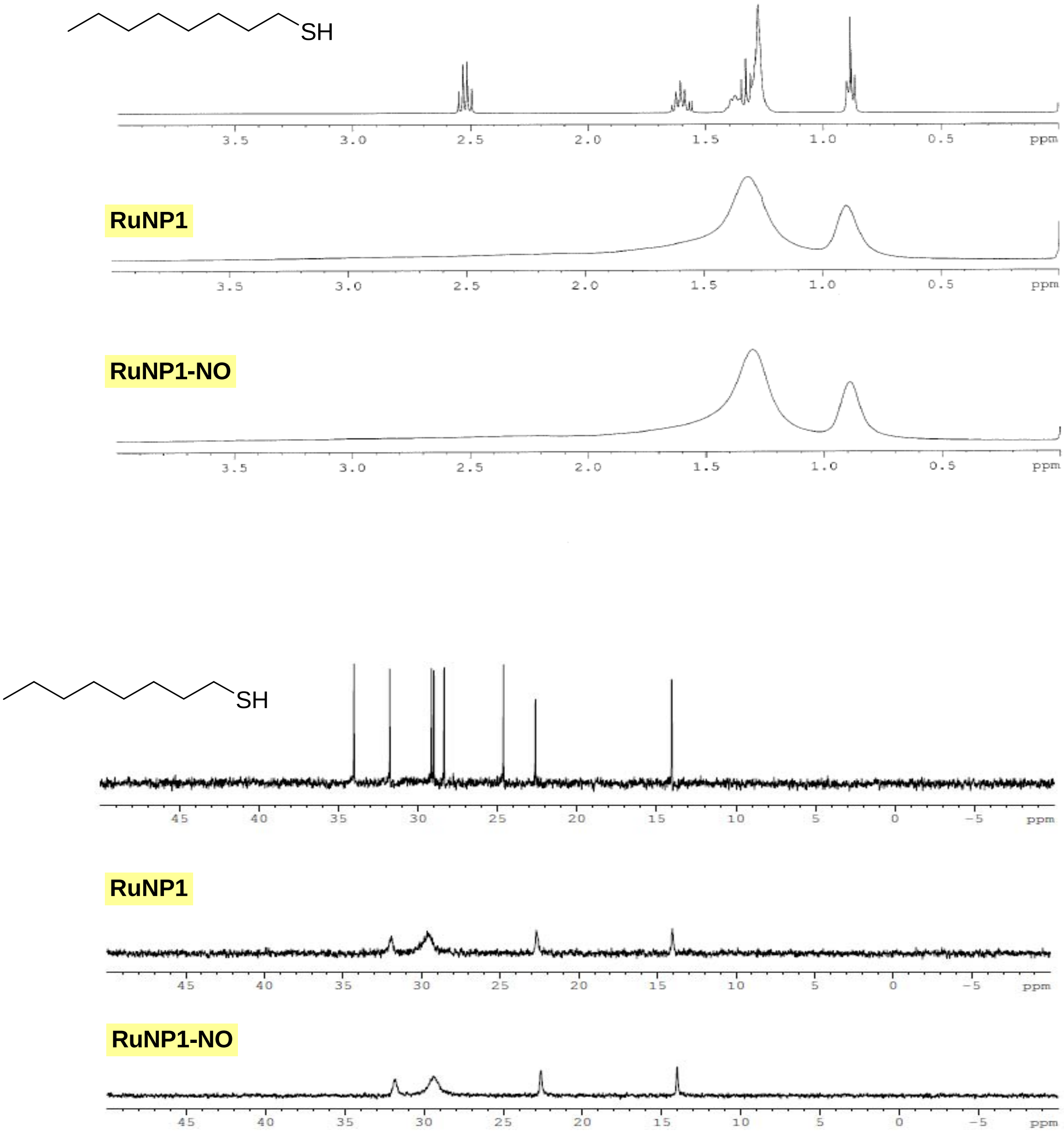
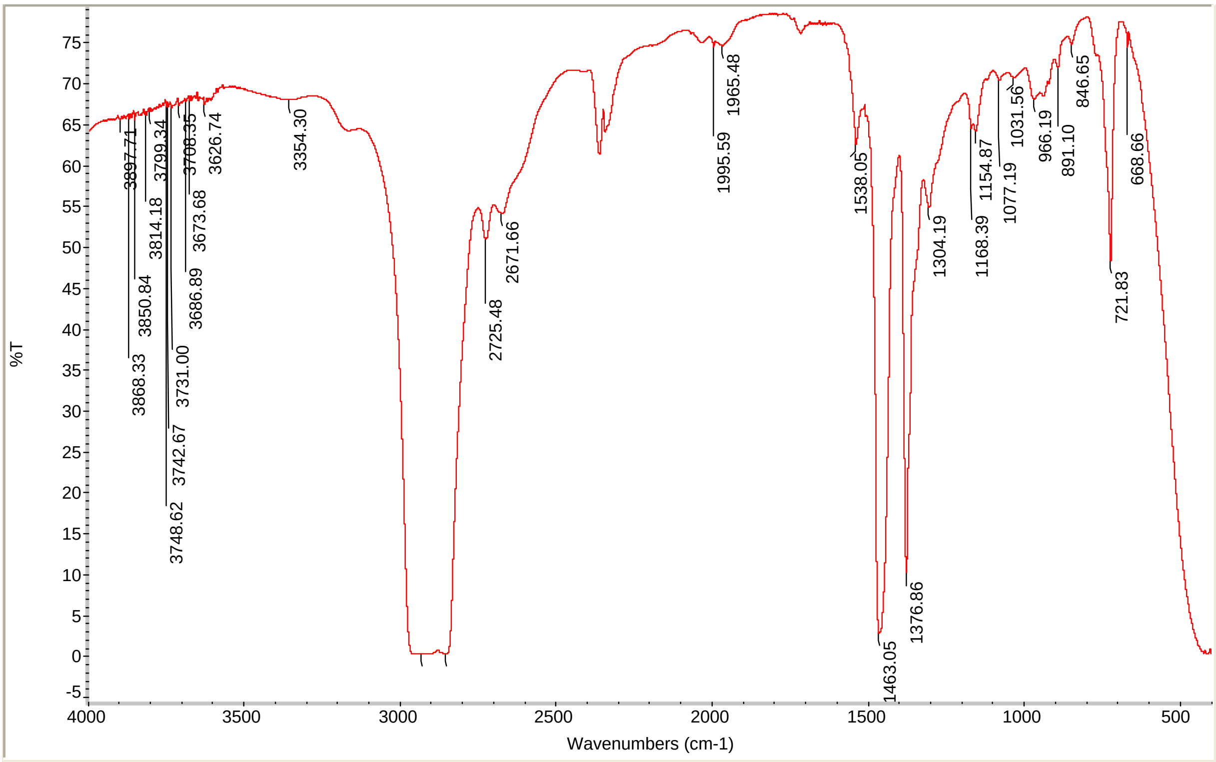


Figure S1. ^1H (upper) and ^{13}C (lower) NMR spectra ($CDCl_3$) of 1-octanethiol, **RuNP1** and **RuNP1-NO**.



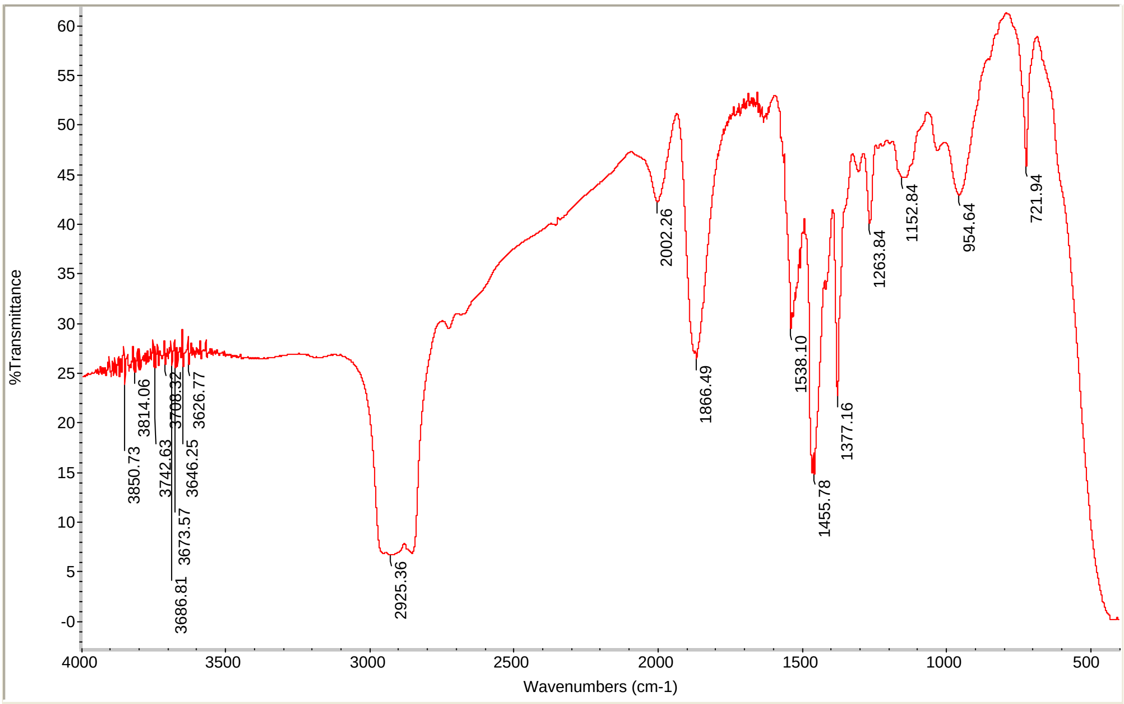


Figure S2. IR spectrum of **RuNP1** (upper) and **RuNP1-NO** (lower).

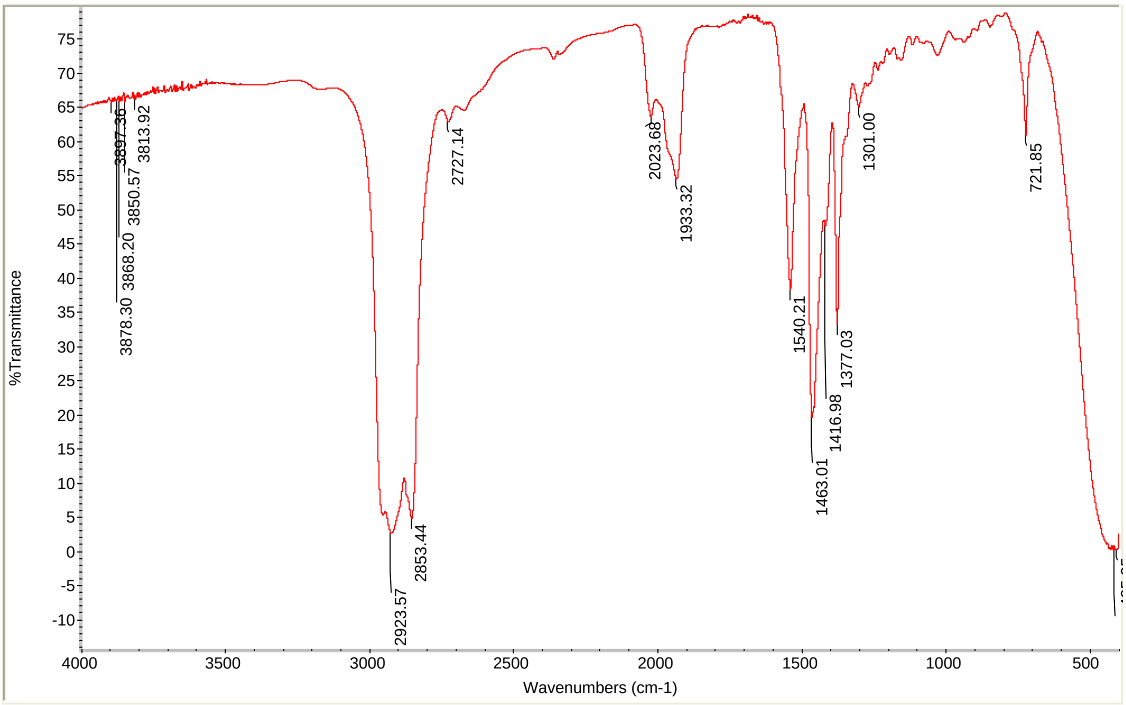


Figure S3. IR spectrum of **RuNP1-CO.**

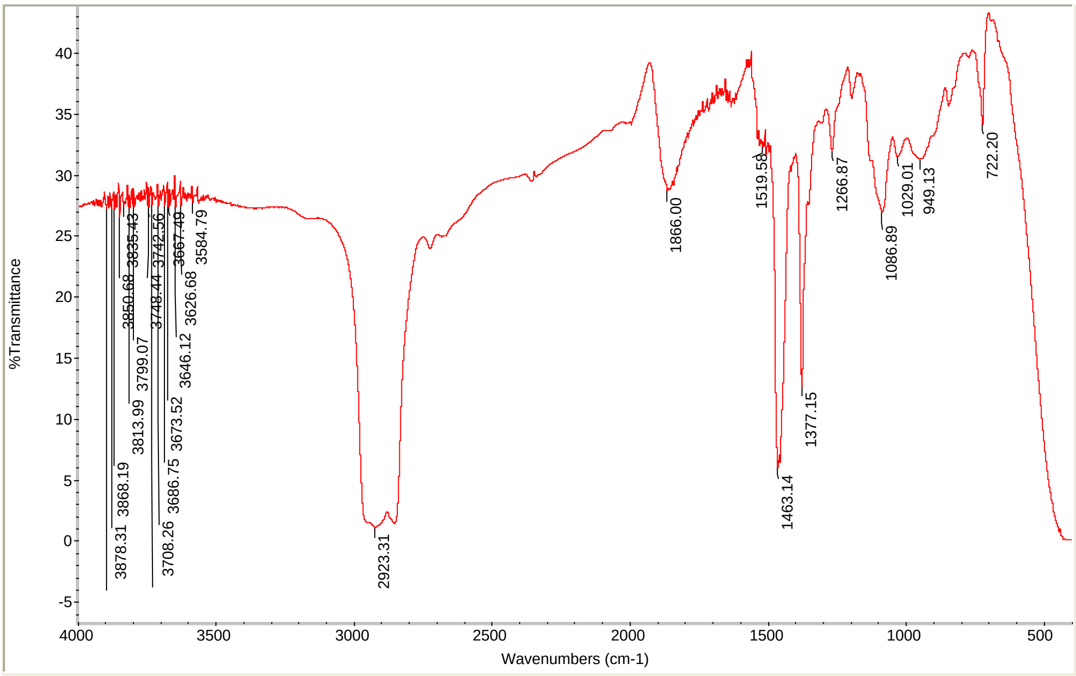


Figure S4. IR spectrum **RuNP2-NO**.

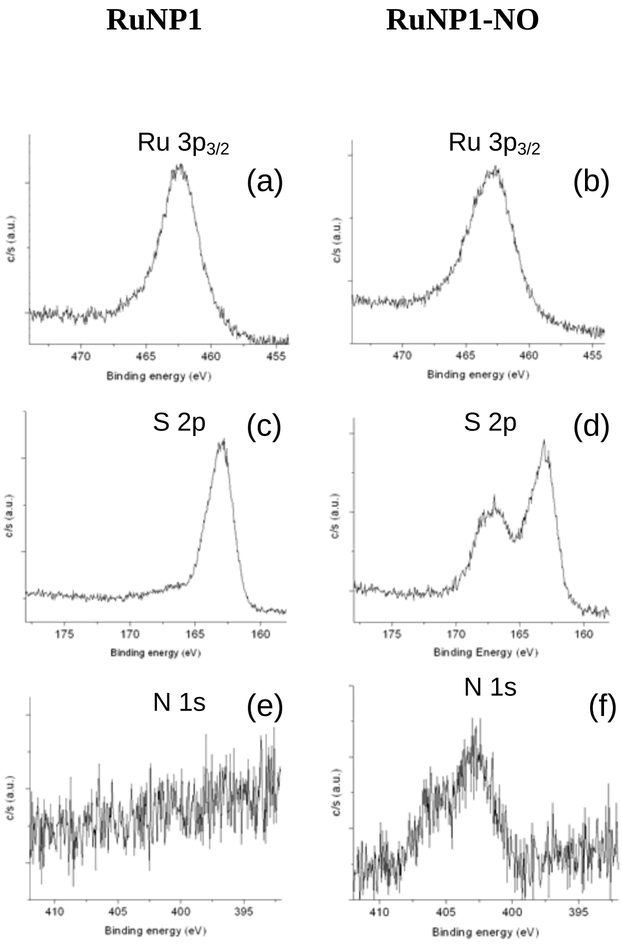


Fig S5. XPS spectra of **RuNP1** (left colmun) and **RuNP1-NO** (right colmun).

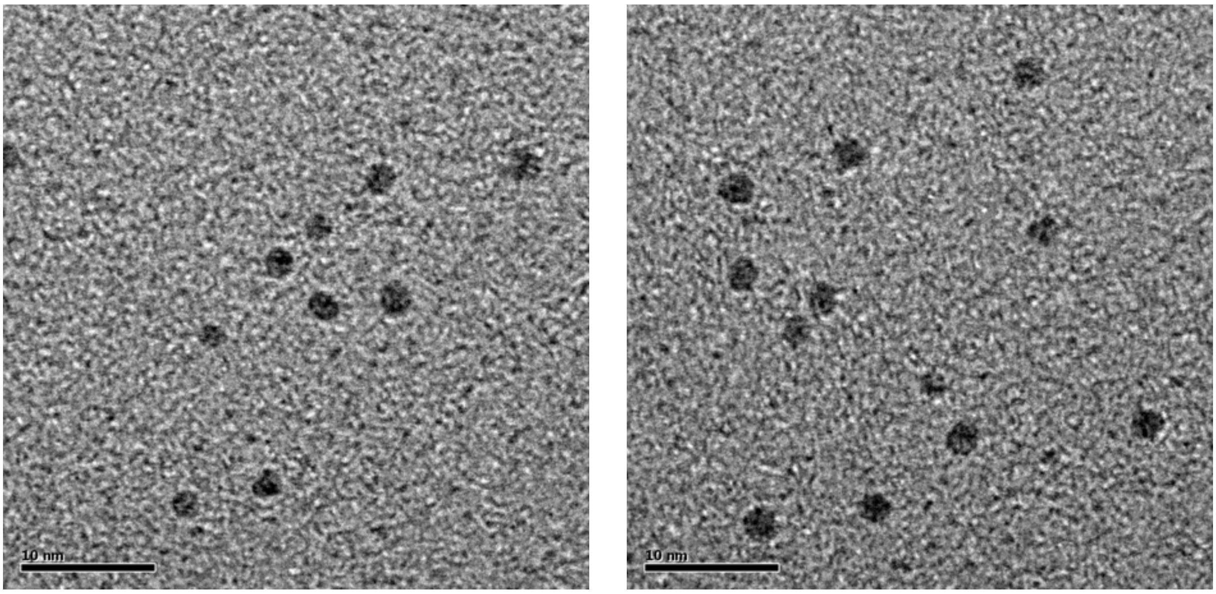


Fig S6. TEM micrographs of **RuNP2** (size: 2.2 ± 0.4 nm, left) and **RuNP2-NO** (size: 2.1 ± 0.4 nm, nm) (right).

NO-Photoreleasing Experiments. Photochemical reactions were carried in a glass vial (Wheaton, 24 ml) containing 20 mL of **RuNP2-NO** (0.1 mg/mL) in phosphate-buffered saline (PBS, pH 7.4) and using a RPR-100 Rayonet photochemical reactor equipped with three Philips F8T5/D fluorescent lamps (8W each). After defined time intervals, 0.5 mL solution was drawn and the amount of NO release was determined by analysis of nitrite concentration with Griess spectrophotometric method.[2] For NO transfer studies, equine skeletal muscle myoglobin was first reduced by dithionite (~ 1.2 equiv). The reduced equine skeletal muscle myoglobin (2 μM) and **RuNP2-NO** (0.1 mg/mL) were placed in a sealed quartz cuvette under Ar atmosphere. The sample was irradiated with the fluorescent lamps for 30 min and the spectra were recorded on Hewlett-Packard 8543 diode array spectrophotometer.

Apparent Quantum Yield Measurements. Chemical actinometry was performed with ferric oxalate solutions.[3] Monochromatic irradiations at 366, 436 and 509 nm were carried out using 300 W Xenon lamp in an Oriel Universal Arc Lamp Source (model 6253) passing through an IR filter and monochromator. A sample of known volume in a quartz 1 cm square cuvette irradiated for defined time periods. The quantum yield for NO photorelease was determined by using the following equation:

$$\Phi_{NO} = \Delta[NO] \times V/\Delta t \times I_0 \times F$$

where $\Delta[NO]/\Delta t$ is the rate of NO formation determined by Griess spectrophotometric method, V is the volume of the irradiated solution, I_0 is the intensity of the incident photons and F is the fraction of the photons absorbed by **RuNP2-NO** at the excitation wavelength.

Assays of Fibroblast Cell Viability

The cell viability was determined based on the procedures previously described.[4] Mouse embryonic fibroblast cells (BALB/3T3; Clone A31, ATCC) were cultured in Eagle's minimum essential medium supplemented with 10 % fetal bovine serum. To evaluate the effect of **RuNP2-NO**, cells were seeded in 96-well plates (8000 cells per well) and cultured in a 5 % CO_2 incubator at 310K. Briefly, **RuNP2-NO** was added 18 h after the seeding of cultures. Three replicate wells were used for each experimental condition. After 12 h of treatment, the culture medium was removed, and cells in each well were fixed with 50 μL of 10% formalin followed by addition of 50 μL of 5 mg/L naphtol blue black stain in acetate buffer. After 30 min, the stain was poured off and the plates were rinsed with distilled water. The dye was then eluted by adding 150 μL of 50 mM NaOH. Absorption of each well was read at 580 nm using a Perkin-Elmer Fusion^{TM} α-FP plate reader. Results are expressed as mean of (± SD) of three individual values.

References

1. G. Viau, R. Brayner, L. Poul, N. Chakroune, E. Lacaze, F. Fievet-Vincent, F. Fievet, *Chem. Mater.* **2003**, *15*, 486.
2. (a) L. J. Ignarro, J. M. Fukato, J. M. Griscavage, R. E. Byrns, Proc. *Natl. Acad. Sci. USA* 1993, **90**, 8103. (b) H. H. H. W. Schmitdt, M. Kelm in Methods in *Nitric Oxide Research* (Eds.: M. Feelish, J. S. Stamler), Wiley, New York, 1996.
3. J. G. Calvert and J. N. Pitts, *Photochemistry*, Wiley, New York, 1966.
4. C.-M. Ho, H.-C. Leung, C.-N. Lok and C.-M. Che, *Chem. Asian J.* 2010, **5**, 1965.