Online Supporting Information's for

Electrically Conducting Osmium Nano-chain Networks with Superior Catalytic and SERS Performance

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Instruments.

The synthesized SDS-Os nano-chain networks were characterized with several spectroscopic techniques such as: UV-Vis, TEM, EDS, XRD, XPS and FT-IR analyses as discussed below. The UV-visible (UV-Vis) absorption spectra were recorded in a double beam UV-Vis spectrophotometer purchased from Unico (model 4802) equipped with a 1 cm quartz cuvette holder for liquid samples. The transmission electron microscopy (TEM) analysis was performed with JEOL-JEM 2010 and Tecnai model TEM instrument (Tecnai[TM] G2 F20, FEI) with an accelerating voltage of 200 KV. The Energy Dispersive X-ray Spectroscopy (EDS) analysis was performed with the SEM instrument (Tescan) with a separate EDS detector connected to that instrument. A thin film of the Os nano-chain networks solutions was made on a glass substrate and the fabricated thin films were characterized by X-ray diffraction (XRD), and Fourier Transform Infrared Spectroscopy (FT-IR) analyses. The XRD analysis was done with a scanning rate of 0.020 s^{-1} in the 2θ range 30-80° using a PAN analytical Advanced Bragg-Brentano X-ray powder diffractometer (XRD) with Cu Kα radiation ($\lambda = 0.154178$ nm). The FT-IR analysis was performed with the model Nexus 670 (FT-IR), Centaurms 10X (Microscope) having spectral range 4,000 to 400 cm^{-1} with a MCT-B detector. The XPS analysis was carried out using an ESCA model VG 3000 system X-ray photoelectron spectrometer with monochromatic Mg K$_\alpha$ line (1253.6 eV)

radiation. The instrument integrates a magnetic immersion lens and charge neutralization system with a spherical mirror analyzer, which provides real time chemical state and elemental imaging using a full range of pass energies. The emitted photoelectrons were detected by the analyzer at a passing energy of 20 eV with energy resolution of 0.1 eV. The incident X-ray beam was normal to the sample surface, and the detector was 45° away from the incident direction. The analysis spot on the sample was 0.4 mm × 0.7 mm. The overall energy resolution was about 0.8 eV. Samples for the survey spectrum was recorded in the 0 – 700 eV kinetic energy by 1 eV steps where as high resolution scans with 0.1 eV steps were conducted over the following regions of interest: Os 4f, O 1s and C 1s. The surface enhanced Raman scattering (SERS) study was done with Renishaw in Via Raman Microscope using an excitation wavelength of 632.8 nm (He-Ne laser). The excitation light intensity in front of the objective was ~10 mW with a spectral collection time of 1 sec for both Raman and SERS experiment. The integration time for our measurement was set to 10 sec. The conductivity (I-V, current-voltage) study was performed with a custom built setup which allowed two point measurements across Au pads.
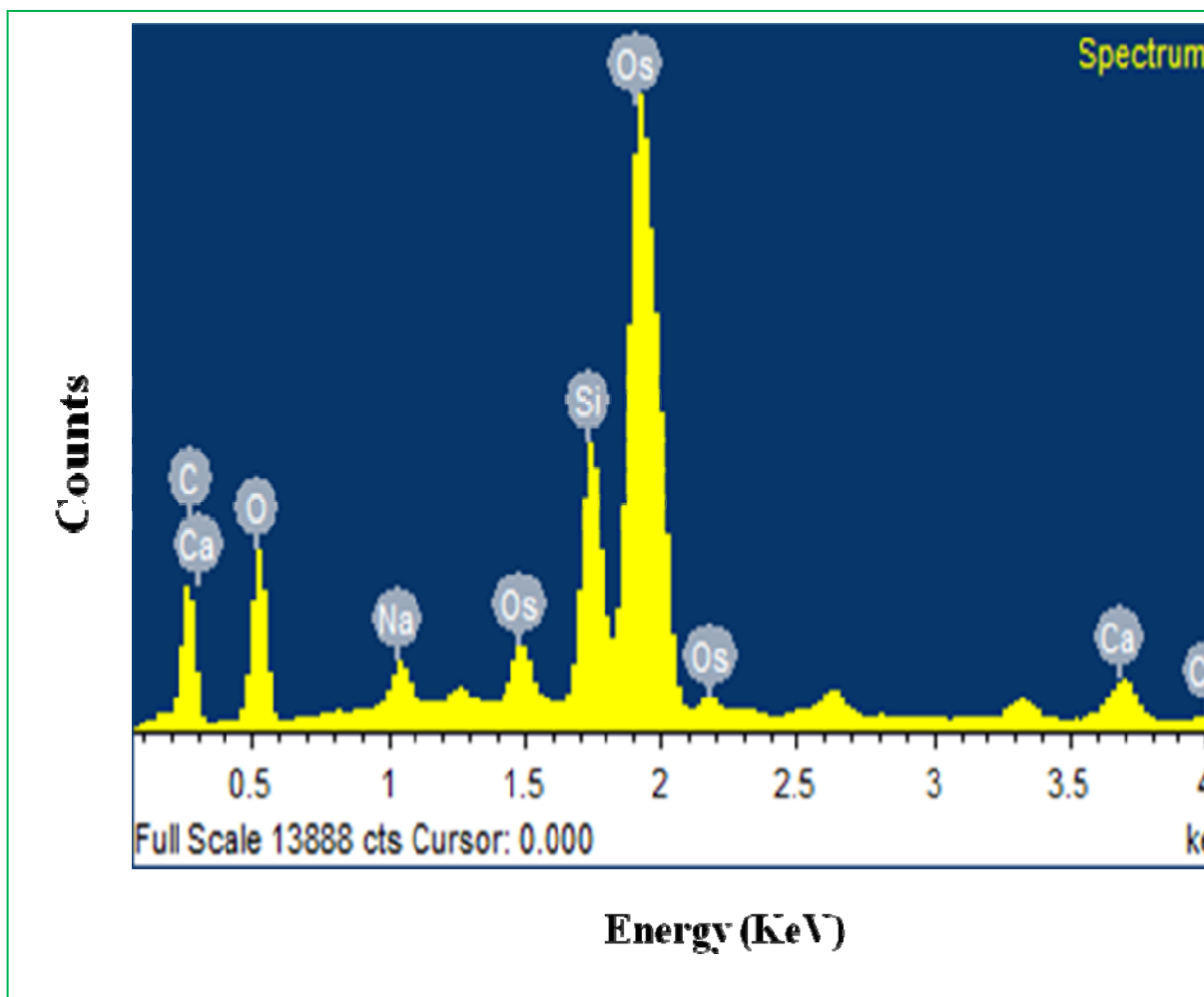
Figure S-1: The energy dispersive X-ray spectroscopic (EDS) analysis of the Os nano-chain network synthesized in SDS micellar medium containing different peaks for Ca, Si, O, Na and Os.
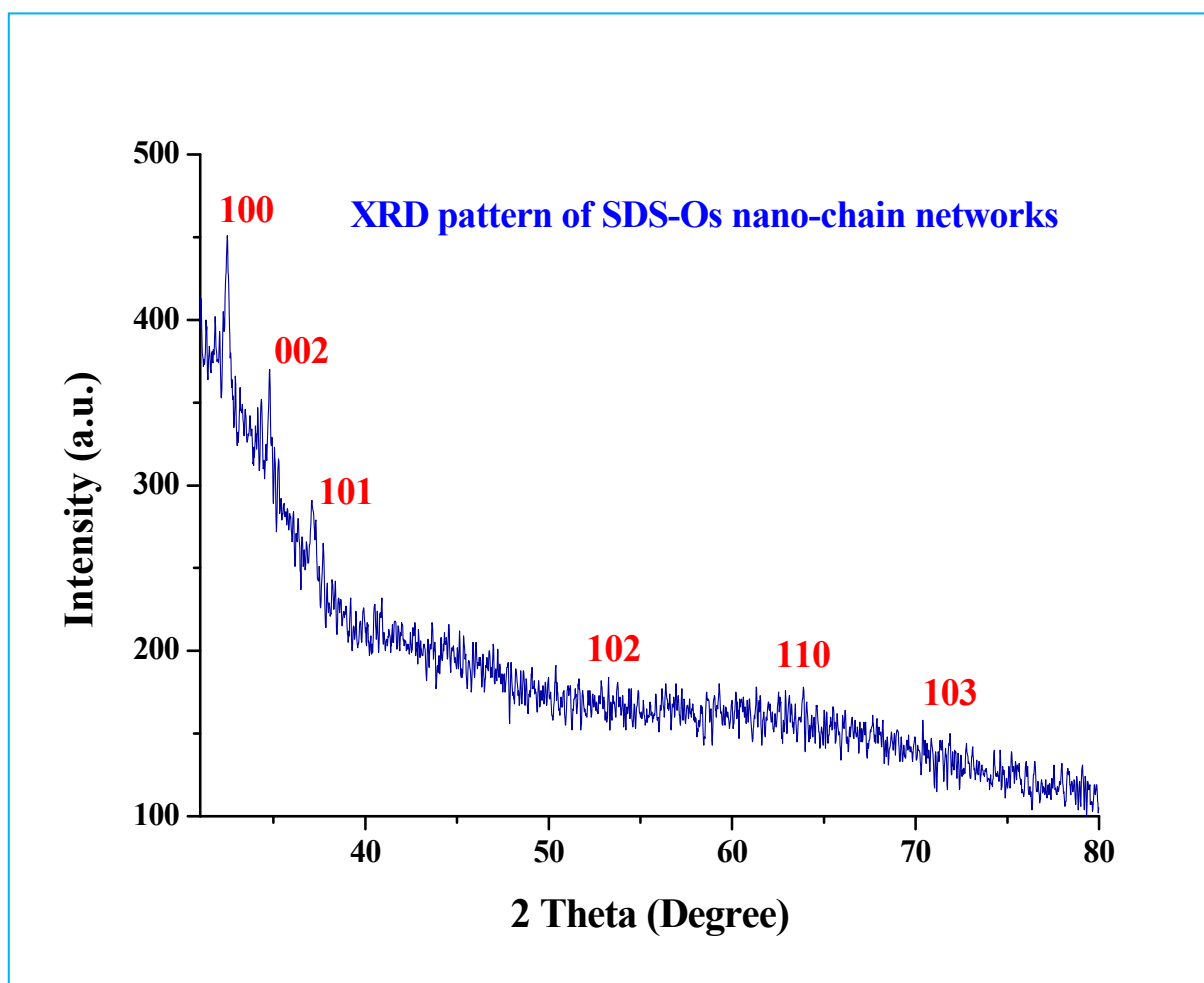
Figure S-2: The X-ray diffraction patterns of the SDS-Os nano-chain network containing different peaks diffracted from (100), (002), (101), (102), (110) and (103) planes of hexagonal phases of osmium NPs.
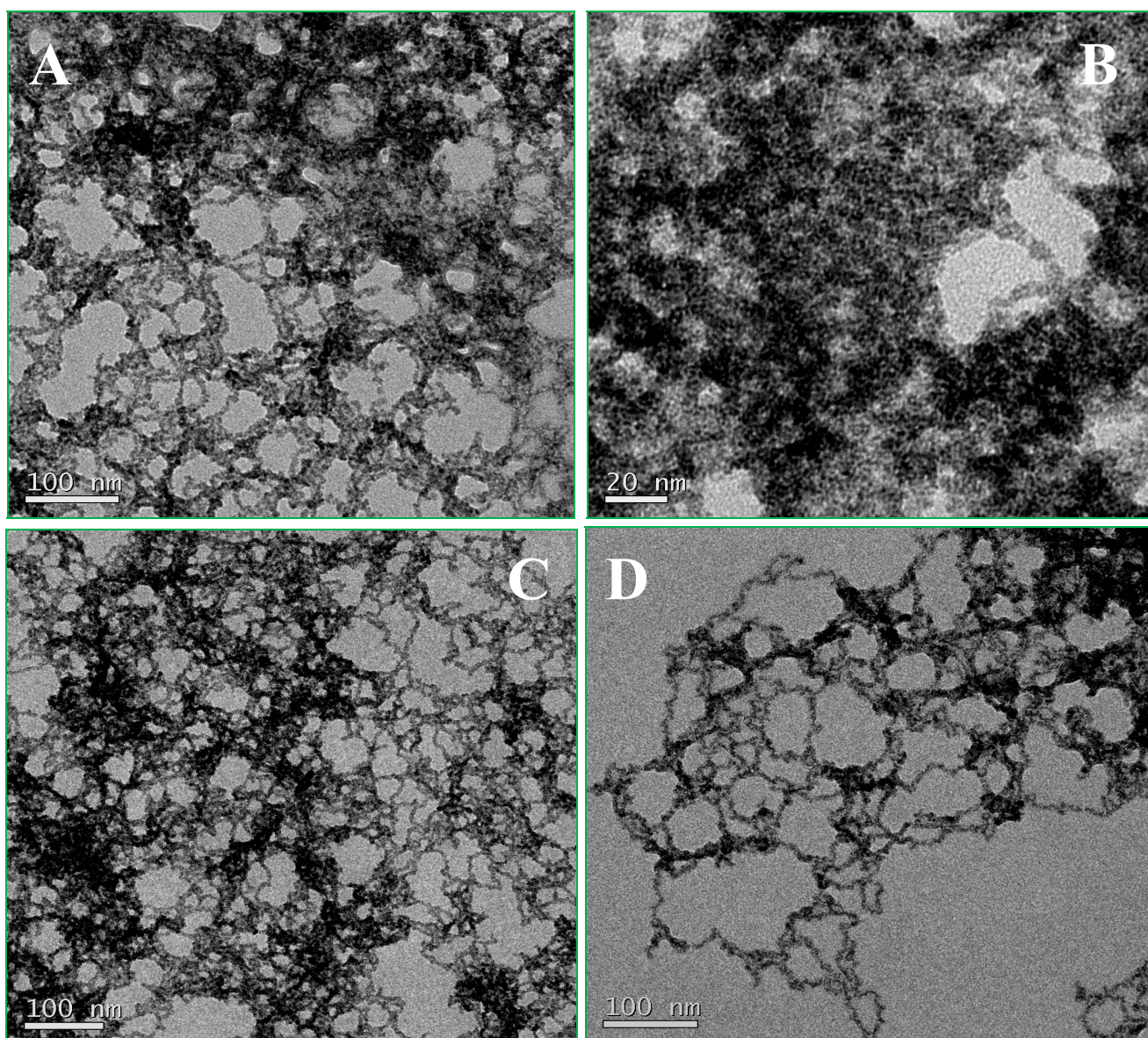
Figure S-3: The transmission electron microscopy (TEM) images of the SDS-Os particles at different reaction conditions. (A) shows the TEM image of Os NPs while SDS concentration is very high; (B) shows the image of Os NPs when Os salt concentration is high; (C) shows the image of aggregated Os NPs while $NaBH_4$ concentration is very high; (D) shows the image of Os NPs while keeping the reaction for 3-4 hours stirring .
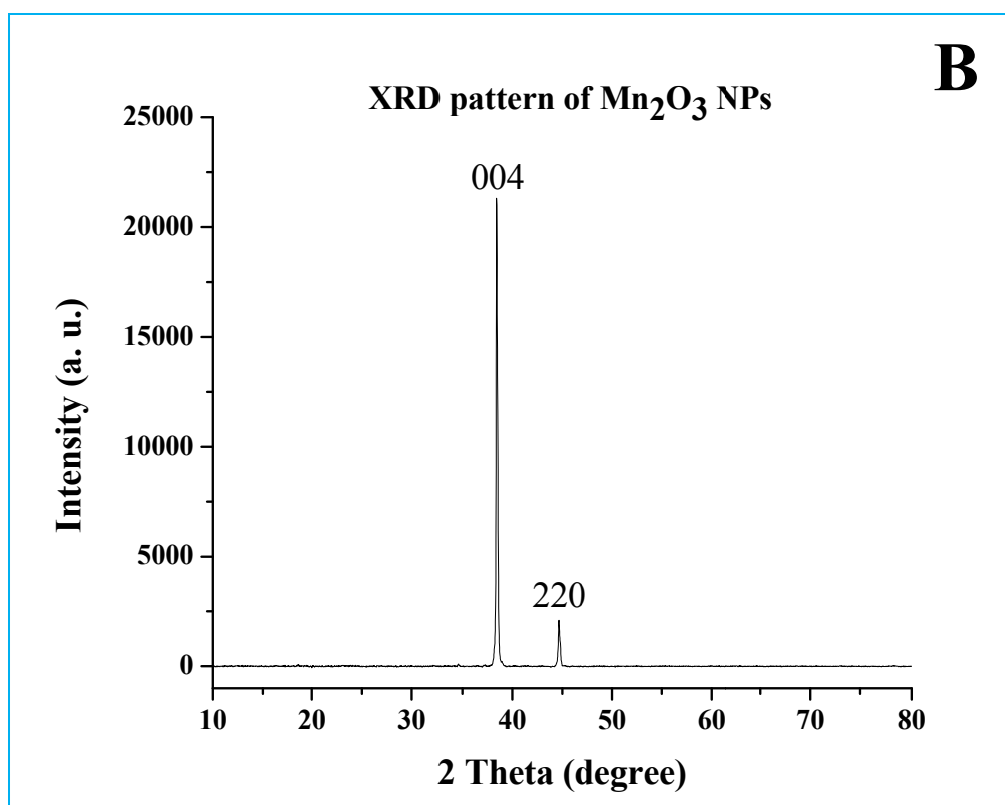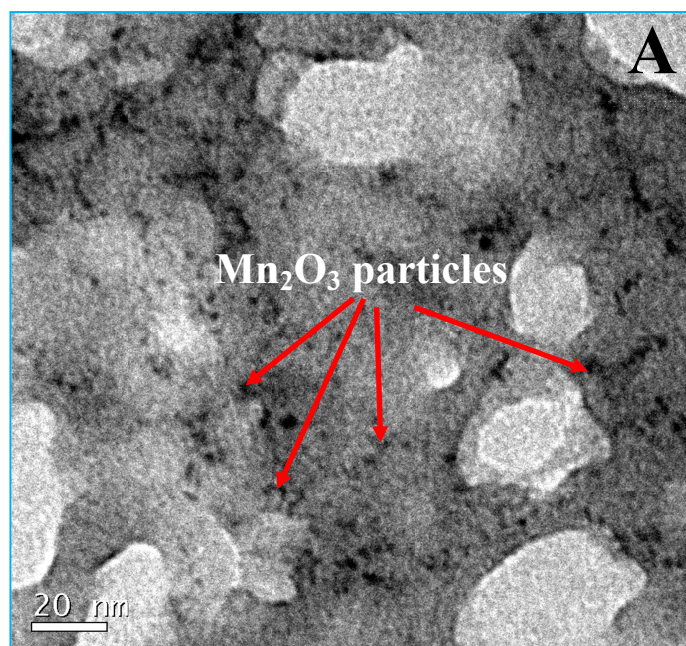
Figure S-4: **(A)** The transmission electron microscopy (TEM) images of the Mn_2O_3 particles. Inset shows the SAED pattern. (B) XRD pattern of Mn_2O_3 particles.

Calculations of Enhancement Factor (EF) were given details as reference 29 in main text. A further elaboration is given below.

The SERS EF is calculated according to the following equation:

$$EF = \frac{(I_{SERS}/C_{SERS})}{(I_{RS}/C_{RS})}$$

Where, I_{SERS} = intensity of enhanced spectrum, C_{SERS} = concentration of the dye while capturing the SERS spectrum, I_{RS} = intensity of the normal Raman spectra (only dye molecules) and C_{RS} = concentration of the dye while taking the normal Raman spectrum.

The calculation of C_{SERS} was done as:

1000 ml of 5×10^{-9} M analyte contains 6.023×10^{23} number of molecules.

1 ml of 1 M contains $= 5 \times 10^{-9} \times 6.023 \times 10^{23}/1000 = 3 \times 10^{12}\ 10^{23}$ number of molecules.

10 µl contains $= 3 \times 10^{10}$ number of molecules.

Approximate diameter of the spot while depositing for SERS analysis on glass substrate ~ 3 mm.

Number of molecules per area $= 3 \times 10^{10}/\pi r^2$

The diameter of the LASER spot was ~ 1 µm.

So the number of molecule present inside the LASER spot was ~ 4.2×10^3.

In this calculation we used different concentration of C_{SERS} so the number of molecule present inside the LASER spot also will change. Here we assumed that the maximum number of MB molecules bonded on the Osmium NPs and EF values were calculated accordingly. But it is not easy to predict exactly about how many number of MB molecule bonded on Osmium NPs.