

Title: Magnetic chains of metal formed by assembly of small nanoparticles

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Supporting Information

S1. Sample characterization

X-ray powder diffraction (XRD, Rigaku, Dmax2200, Cu- $k\alpha$) was used for the structural determination. Further microstructural and elemental analyses were performed using a scanning electron microscope (SEM) (JSM-5800 with accelerating voltage of 15 kV) and an analytical transmission electron microscope (TEM) (Tecnai F30 TEM with field emission gun and accelerating voltage of 300 kV, FEI Company). Room-temperature magnetic characterization of the chain-like nickel network was performed using a model 9600 vibrating sample magnetometer (VSM), under a test field range of -4000 to 4000 Oe. The Curie temperature (T_c) of the sample was determined at the inflection point of the curve.

S2. Magnetic properties

Magnetic properties of the branched Ni nanoparticle chains were investigated by a VSM (vibrating sample magnetometer) technique. Even at room temperature, a pronounced hysteresis loop is measured as seen in Fig. S1, which is a clear sign of ferromagnetic response. Several features in Fig. S1 are worth noticing. First, the coercivity value amounts to 16 mT for Ni nanoparticle chains, which are over two orders of magnitude larger than that of bulk Ni (0.07 mT) ^[1]. One can expect that the reduced

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size and dimensionality of the Ni nanostructures may change the magnetization reversal mechanism, leading to the large enhancement of coercivity. This is interesting for future application of magnetic recording devices. Second, the magnetization hysteresis loop is symmetric with respect to the zero field. This suggests that there is no exchange biasing effect ^[2] caused by NiO ($T_N = 520$ K) ^[1], because the exchange coupling between ferromagnetic Ni and the adjacent antiferromagnetic NiO would otherwise result in a shift of the hysteresis loop. Again, this indicates that the samples have no significant oxidization during and after the preparation. However, the saturation magnetization (M_s) (50.17 emu/g) of the as prepared product is slightly less than that of the bulk fcc Ni (~55 emu/g). We also found the Curie temperature of the same sample to be 345.7°C (Fig. S2), which is lower than that of the bulk nickel (358°C). Conceivably, the lowered magnetization may result from the surface effect of the nanoparticles, and/or from the interaction between the dangling nickel atoms and the PVP molecules. Similar phenomena were found as well in other magnetic nanomaterials such as Fe ^[3, 4, 5].

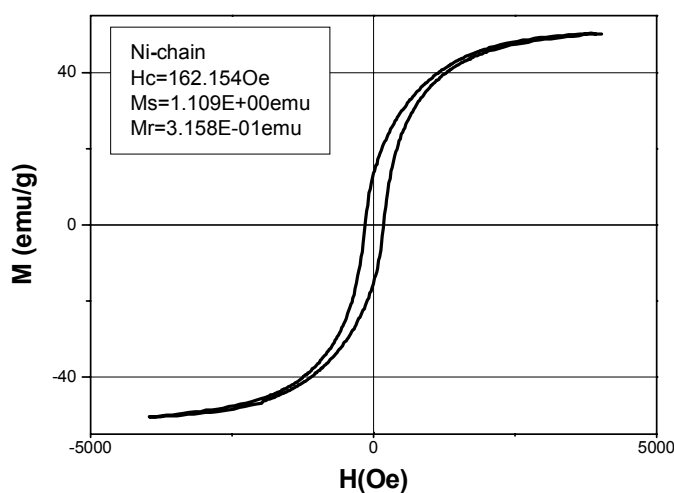


Fig. S1. Magnetization loop at 300 K for the fractal network of Ni nanoparticle chains.

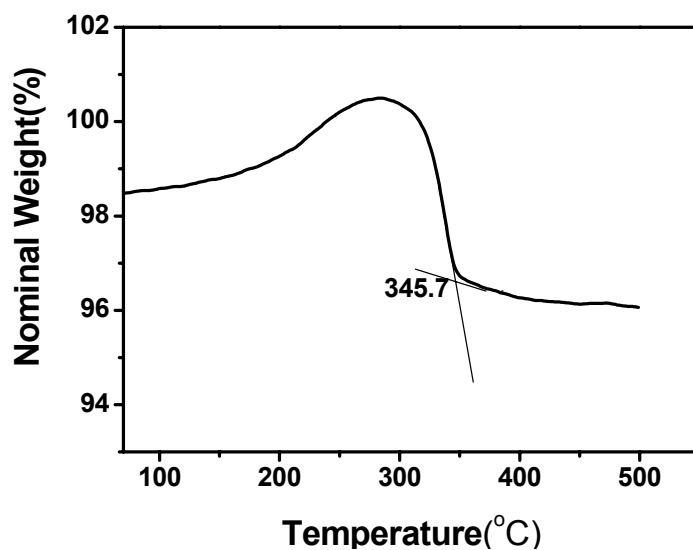


Fig. S2. Measurement of the Curie temperature.

1. Bozorth, R.M., *Ferromagnetism*, D. Van Nostrand Company, Inc, Toronto, New York, London, **1951**.
2. Nogues, J. and I. Schuller, K., *J. Magn. Magn. Mater.* **1999**, *192*, 203.
3. Ely, T.O., Amiens, C., Chaudret, B., *Chem. Mater.* **1999**, *11*, 526.
4. Wilson, K.S., Harris, L.A., Goff, J.D., Riffle, J.S. and Dailey, J.P., *European Cells and Materials*, 2002, *3*, Suppl.2, 206
5. Suslick, K.S., Fang, M., and Hyegon, T., *J. Am. Chem. Soc.* **1996**, *118*, 11960

S3. Extension of the method to the synthesis of Co nanoparticle chains

We have testified the generality of our method by carrying the synthesis but using $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ instead of $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$. Similar pure cobalt nanoparticle chains were obtained in this case as shown in Fig. S3.

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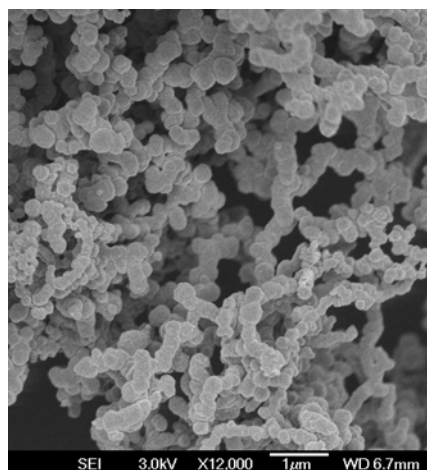


Fig. S3 Cobalt nanoparticle chains synthesized using the same procedure except for the usage of $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$.

S4. Evolution from Ni nanoparticles to Ni chains during refluxing

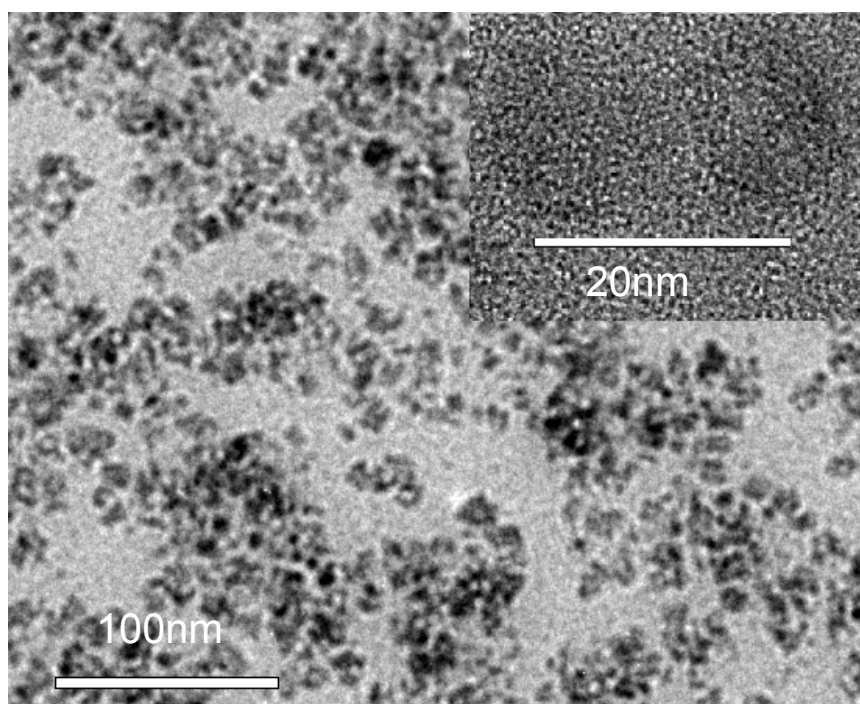


Fig. S4 TEM image of Ni nanoparticle products obtained after refluxing for 0.5 h. Inset: An enlarged view of two nanoparticles.

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For a shorter refluxing time (e.g., half an hour), the Ni nanoparticles are very small. The inset shows a blow-up of the nanoparticles. The average size of the small particles is estimated to be about 10 nm. The bigger nanochains described in the text were assembled from these small nanoparticles. Namely, the small Ni nanoparticles were aggregated to form larger nanoparticles, which were aggregated further to form the nanochain networks.

S5. Lattice-resolved HRTEM image of fused Ni nanoparticles

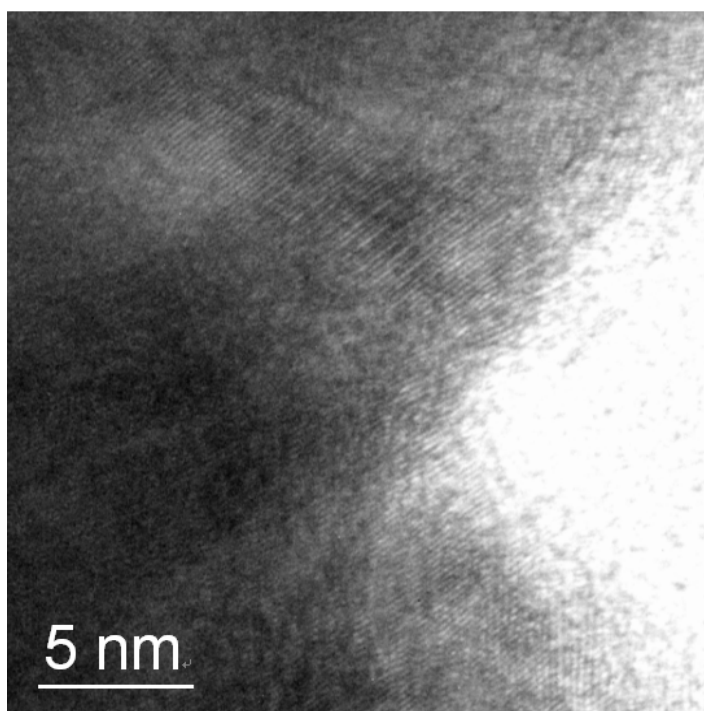


Fig. S5 Enlargement of Fig. 2c in the text showing the Ni nanoparticle contact region.

As stated in the text, the lattice fringes prolongate across the two nanoparticles without interruption by an apparent boundary.