Supplementary Information (SI) for Journal of Materials Chemistry C.

Supporting Information

One-dimensional Cu-Ni Core-shell Composites as Liquid Epoxy Molding Compound Fillers for Enhanced Heat Dissipation and Electromagnetic Interference Shielding in High-bandwidth Memory

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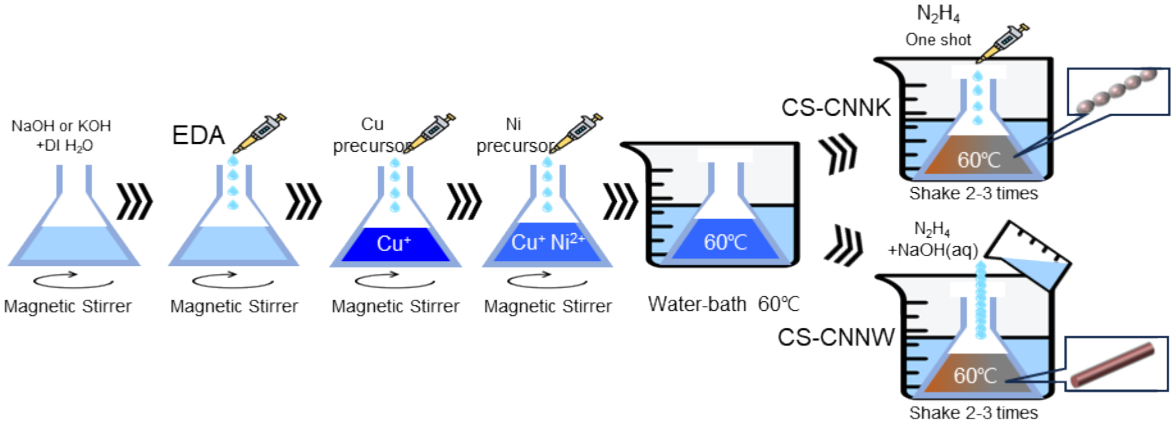

Fig. S1. Schematic diagram of the synthetic methods for 1D CS-CN nanoparticles.

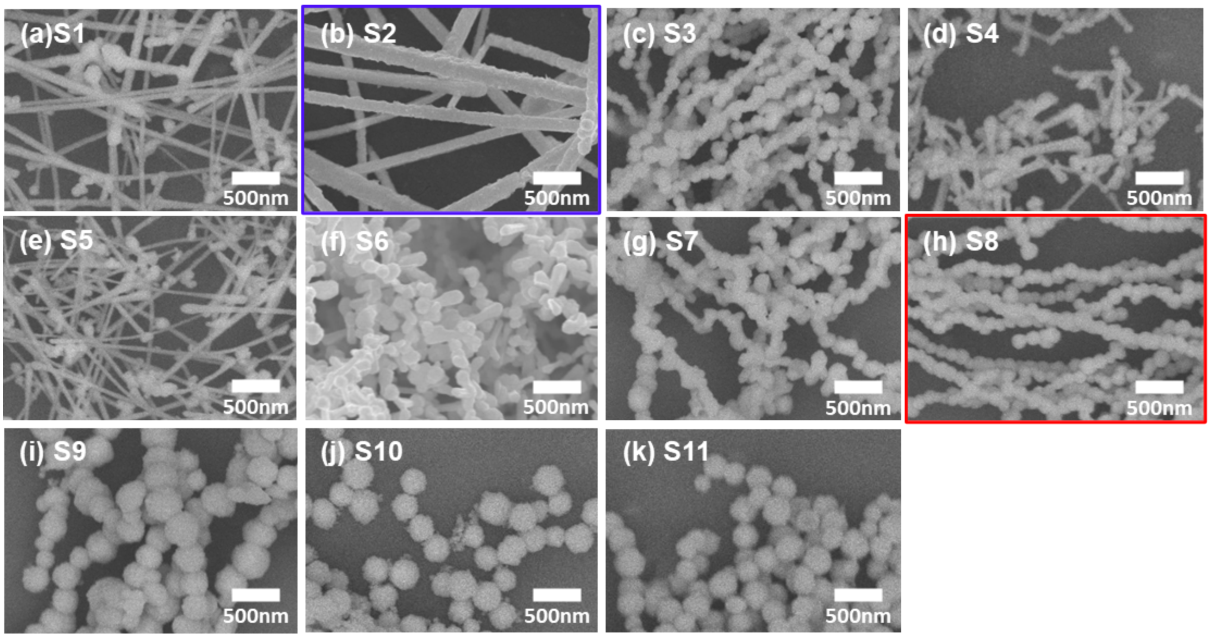

Fig. S2. Case study on the morphology of the resulting CS-CN nanoparticles under various experimental conditions as detailed in Table S1.

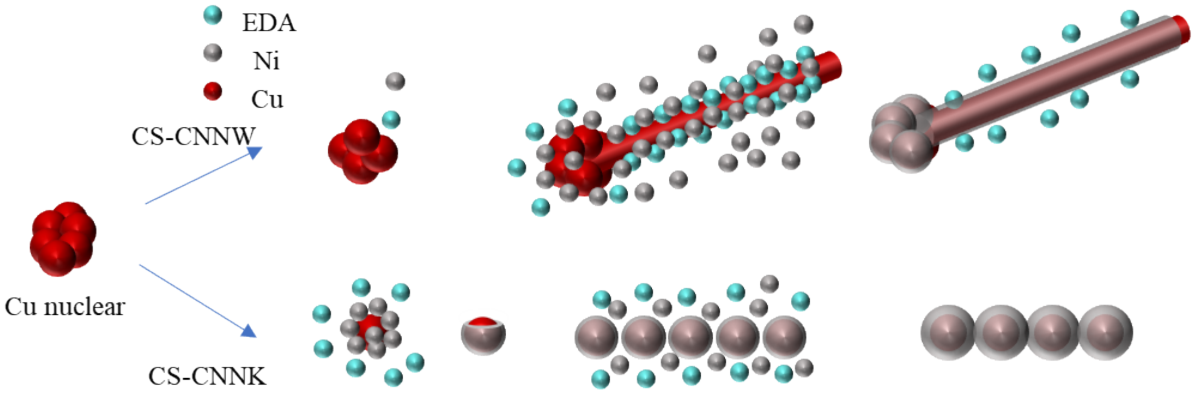

Fig. S3. Schematic illustration of the morphological changes in CS-CNNW and CS-CNNK.

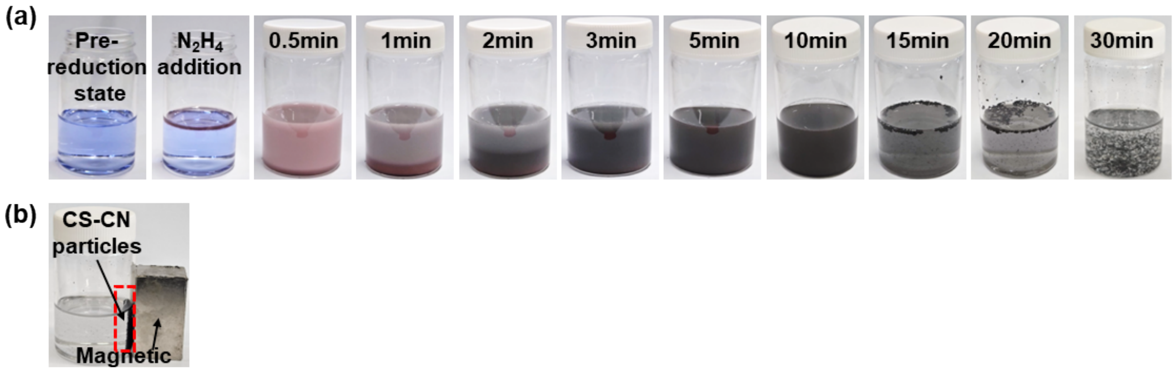

Fig. S4. (a) Time-dependent digital images of reactant mixtures after N_2H_4 injection and (b) digital image of as-synthesized CS-CNNK particles attracted to a magnet.

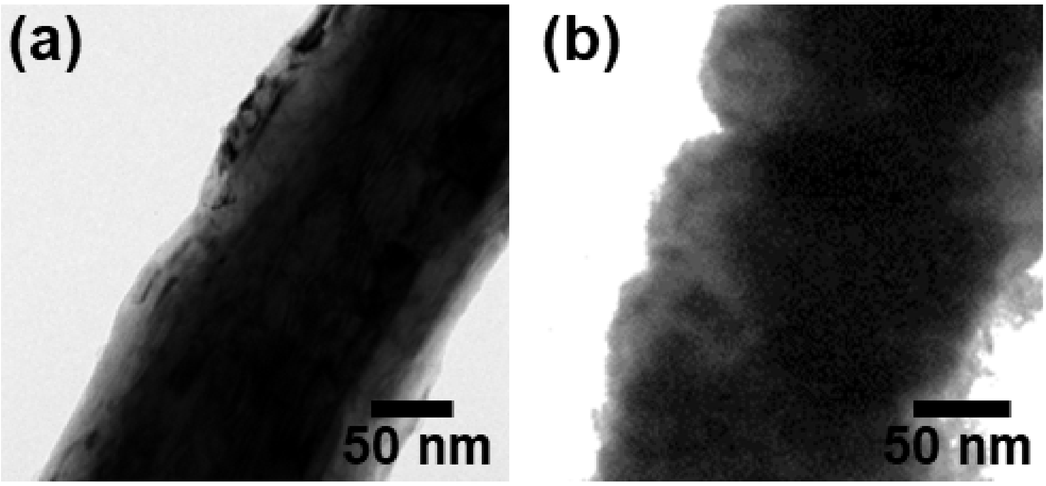

Fig. S5. (a) TEM images of (a) CS-CNNW and (b) CS-CNNK.

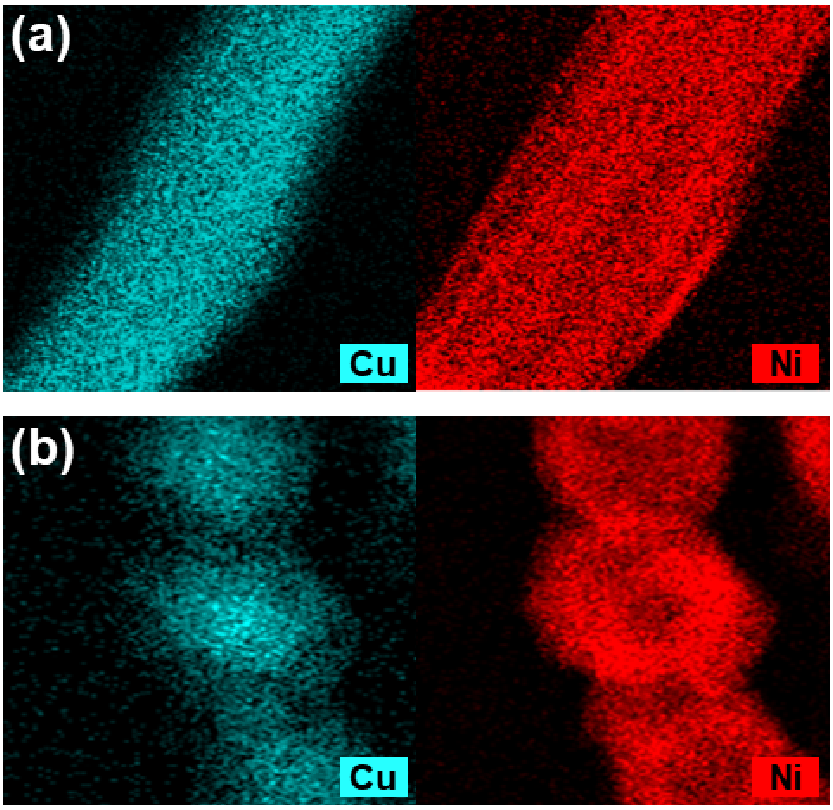

Fig. S6. EDS mapping images of (a) CS-CNNW and (b) CS-CNNK.

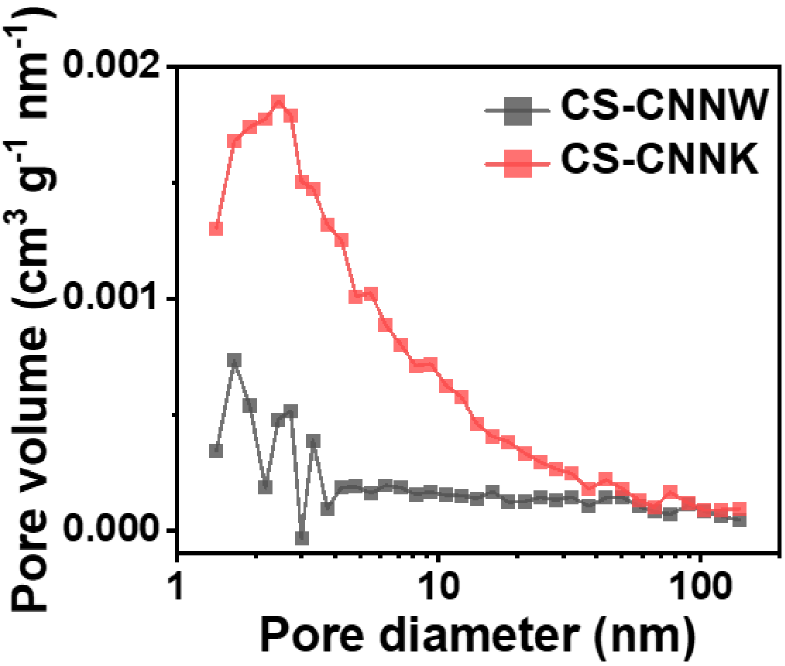

Fig. S7. BJH results for CS-CNNW and CS-CNNK.

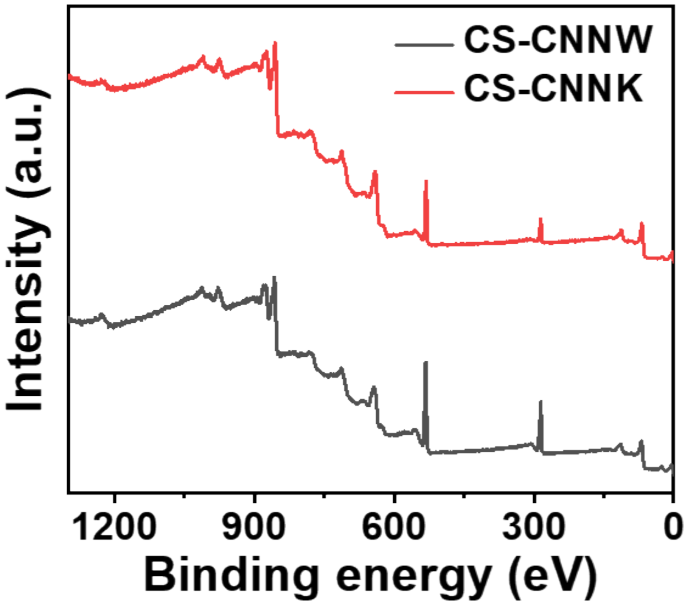

Fig. S8. XPS survey spectra of CS-CNNW and CS-CNNK.

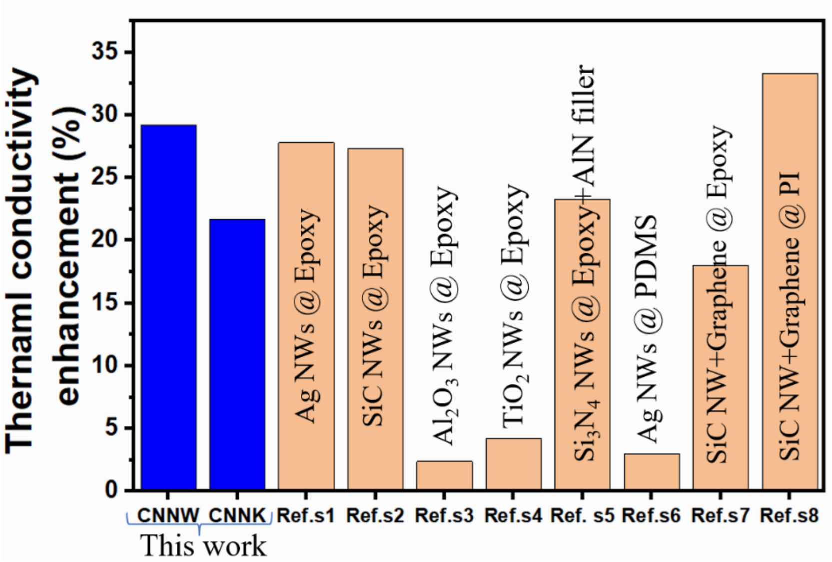

Fig. S9. Comparison plot of thermal conductivity enhancement, as shown in Table S5.

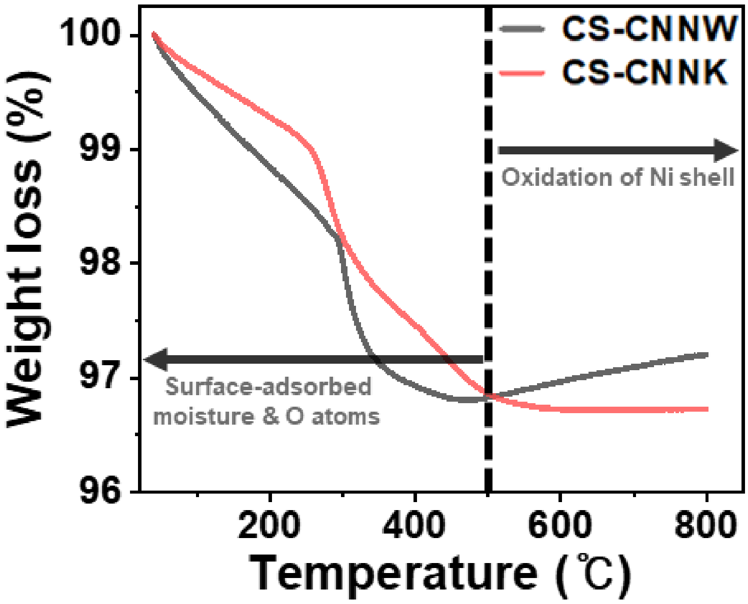

Fig. S10. TGA results for CS-CNNW and CS-CNNK.

Table S1. Case study for the morphology and yield optimization of 1D CS-CN nanoparticles.

Sample	Base solution	Molarity (M)	Cu precursor	Ni precursor	Reductant injection type	Yield	Morphology
S1	NaOH	7	$Cu(NO_3)_2\cdot 3H_2O$	$Ni(NO_3)_2\cdot 6H_2O$	Mixing	61%	CS-CNNW (non-uniform)
★S2	NaOH	7	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	Mixing	84%	CS-CNNW (uniform)
S3	NaOH	7	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	One shot	92%	CS-CNNK (non-uniform)
S4	KOH	7	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	Mixing	71%	Nanoroad
S5	KOH	4	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	One shot	54%	CS-CNNW (non-uniform)
S6	KOH	7	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	One shot	77%	Nanoroad
S7	KOH	10	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	One shot	62%	CS-CNNK (non-uniform)
★S8	KOH	15	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	One shot	88%	CS-CNNK (uniform)
S9	KOH	15	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	Mixing	79%	CS-CNNK
S10	NaOH	15	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	Mixing	60%	Nanoparticle
S11	NaOH	15	$CuCl_2\cdot 2H_2O$	$NiCl_2\cdot 6H_2O$	One shot	33%	Nanoparticle

Table S2. Magnetic properties of CS-CNNK and CS-CNNW obtained from VSM analyses.

Sample	M_s (emu g^{-1})	H_c (Oe)	M_r (emu g^{-1})
CS-CNNW	33.92	222.52	9.58
CS-CNNK	36.71	225.82	6.35

Table S3. Specific surface area and pore volume of CS-CNNW and CS-CNNK obtained from BET and BJH analyses.

Sample	Volume adsorbed (cm^3 g^{-1})	Surface area (m^2 g^{-1})	Average pore diameter (nm)
CS-CNNW	0.37	1.6103	17.765
CS-CNNK	0.6552	2.8519	19.083

Table S4. Details for HBM thermal simulations.

Component	Size (x,y,z) (nm)	Material	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)
Substrate	20, 20, 0.75	FR4	0.294
Base (Logic) die	10.8, 9.8, 0.06	Si	148
Base die bump gap	0.053	Solder + underfill	48
Core die	10.5, 9.5, 0.05	Si	148
Top die	10.5, 9.5, 0.05	Si	148
Core die gap	0.015	LMC	1.2 / 1.55 / 1.46
TSV diameter	0.015	Cu	400
Heat spreader	10.8, 9.8, 3	Al	237.5

Table S5. Comparison of thermal conductivity enhancement with different fillers in LMC and epoxy matrix materials at 1 wt.%.

Matrix	**Material**	**Diameter (nm)**	**Length (um)**	**Thermal conductivity (w/m·k)**			**Ref.**
				0wt%	**1wt%**	**Enhancement**	
LMC	CS-CNNW	250	20	1.2	1.55	29.2%	This work
LMC	CS-CNNK	250	20	1.2	1.46	21.7%	
Epoxy	Ag NWs	110	<50	0.18	0.23	27.8%	S1
Epoxy	SiC NWs	190	120	0.22	0.28	27.3%	S2
Epoxy	Al_2O_3-NWs	5	0.1	0.21	0.215	2.4%	S3
Epoxy	TiO_2 NWs	50	5	0.166	0.173	4.2%	S4
Epoxy+ AlN filler	Si_3N_4 NWs	100	20	0.73	0.9	23.3%	S5
PDMS	Ag NWs	500	20	0.33	0.34	3.0%	S6
Epoxy	SiC NW+Graphene	75	<10	0.2	0.236	18.0%	S7
PI	SiC NW+Graphene	20	10	0.15	0.2	33.3%	S8

Supplementary references

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