Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Facile synthesis of high quality multi-walled carbon nanotubes on novel 3D KIT-6: Application in high performance dye-sensitized solar cells

Jayaraman Balamurugan,[a] Arumugam Pandurangan,[b*] Nam Hoon Kim,[a] Joong Hee Lee [a,c*]

[a]*Advanced Materials Institute of BIN Technology (BK21 plus Global) & Dept. of BIN Fusion Technology, Chonbuk National University, Jeonju, Jeonbuk 561-756, Republic of Korea.*

[b]*Department of Chemistry, Institute of Catalysis and Petroleum Technology, Anna University, Chennai 600 025, India*

[c]*Carbon Composite Research Centre, Department of Polymer & Nanoscience and Technology, Chonbuk National University Jeonju, Jeonbuk 561-756, Republic of Korea*

**Corresponding authors: E-Mail: pandurangan_a@yahoo.com (Arumugam Pandurangan)*
Fax: +91-44-22200660; Tel: +91-44-22358653
E-Mail: jhl@jbnu.ac.kr (Joong Hee Lee)
Fax: +82 832702341; Tel: +82 832702342

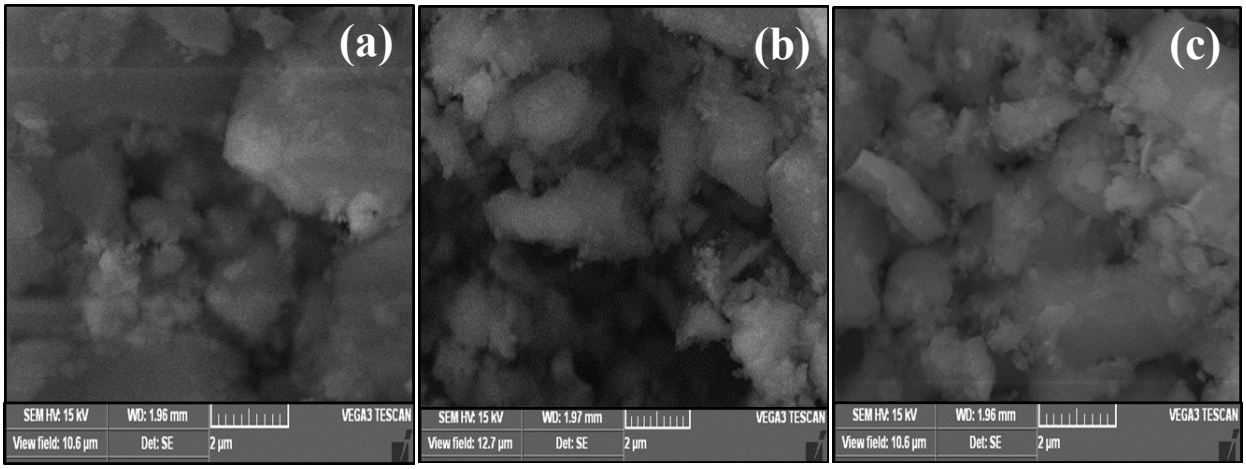

Fig. S1 SEM images of a) Cr-KIT-6, (b) Ni-Cr-KIT-6 and (c) Co-Cr-KIT-6 mesoporous catalysts

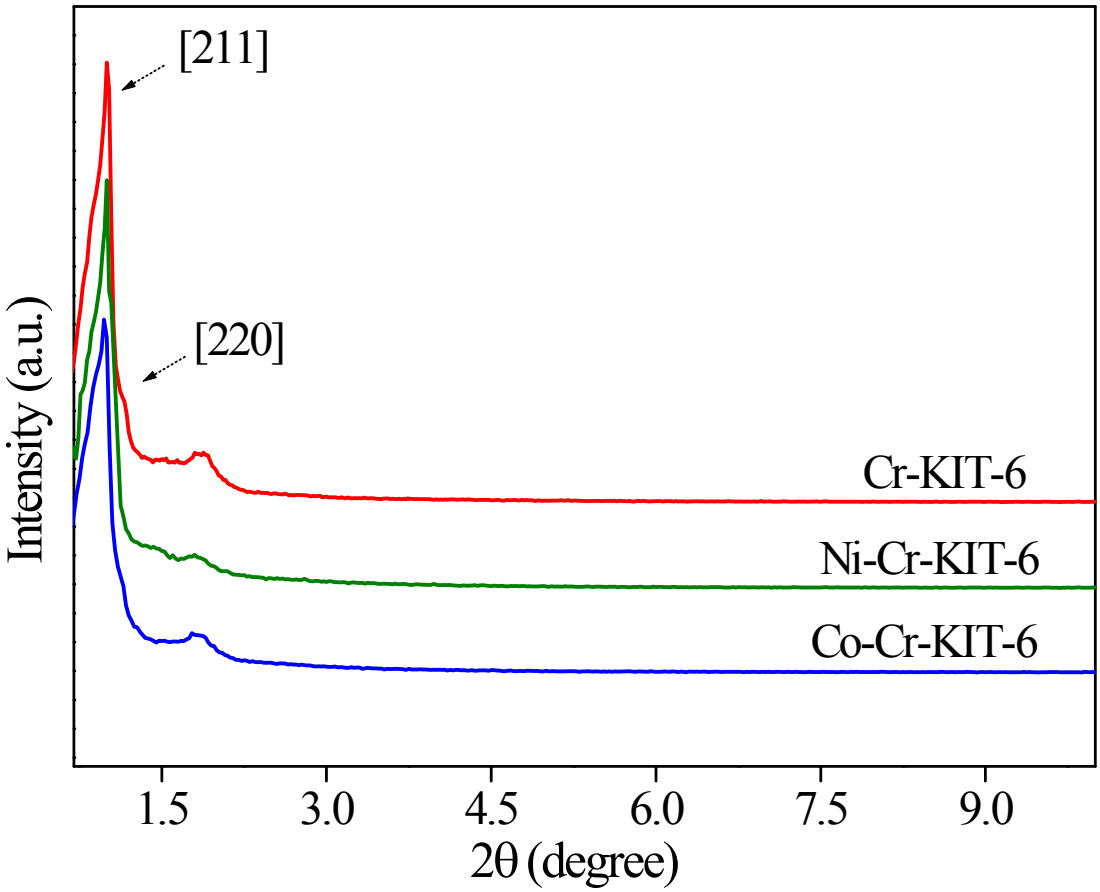

Fig. S2 Small-angle X-ray diffraction patterns of (a) Cr-KIT-6, (b) Ni-Cr-KIT-6 and (c) Co-Cr-KIT-6 mesoporous catalysts

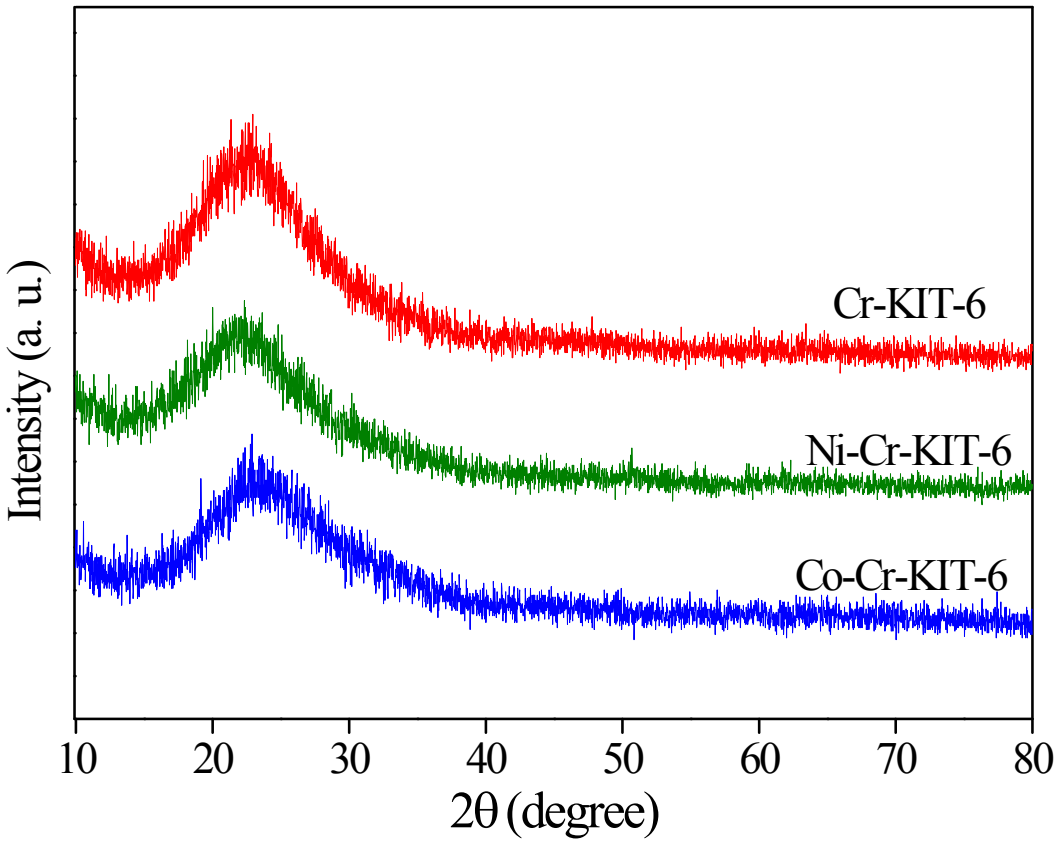

Fig. S3 Wide-angle X-ray diffraction patterns of (a) Cr-KIT-6, (b) Ni-Cr-KIT-6 and (c) Co-Cr-KIT-6 mesoporous catalysts

The FT-IR spectra of the as-synthesized and calcined mesoporous materials (Cr-KIT-6, Ni-Cr-KIT-6 and Co-Cr-KIT-6) are shown in Fig. S4 (a) and Fig. S4 (b), respectively. The broad band appears around 3400–3500 cm^{-1} is due to O–H stretching of surface hydroxyl groups, bridged hydroxyl groups and adsorbed water molecules. The adsorption bands around 2850 and 2975 cm^{-1} corresponds to the symmetric and asymmetric stretching vibrations of $–CH_2$ group of the structure directing template present in the pores of the as-synthesized mesoporous materials. The bands of 2850 and 2970 cm^{-1} are disappeared in the calcined materials. It reveals that the template is fully removed from the mesoporous materials. The band between 450 and 1250 cm^{-1} are assigned to the frame work vibrations of mesoporous materials [S1]. The asymmetric stretching vibrations of Si-O-Si and Si-O-M groups are observed between 950 and 1250 cm^{-1} and the corresponding symmetric stretching modes are observed between 50 and 800 cm^{-1}, the band at 460 cm^{-1} is assigned to bending mode of Si-O-Si and Si-O-M groups in their respective mesoporous 3D KIT-6 materials.

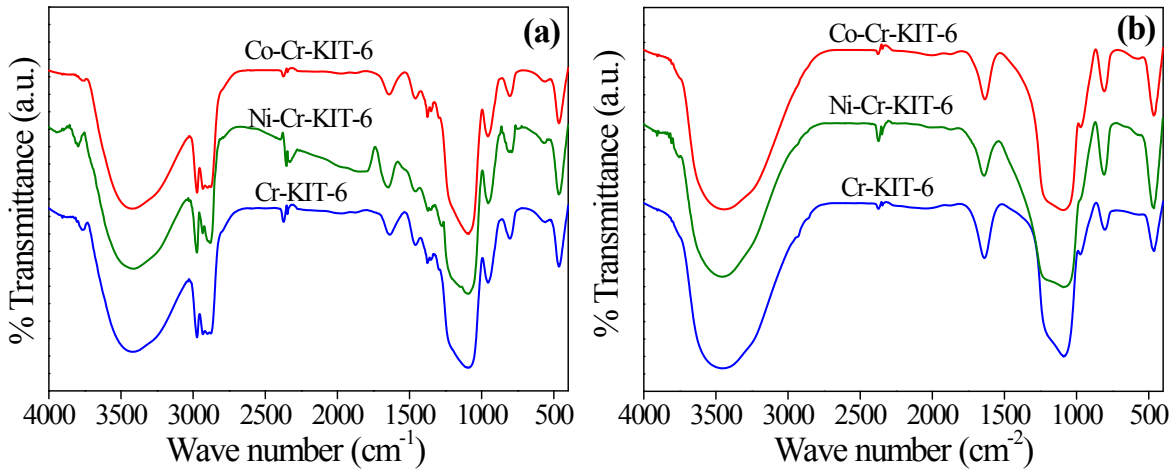

Fig. S4 FT-IT spectra of (a) as-synthesized and (b) calcined Cr-KIT-6, Ni-Cr-KIT-6 and Co-Cr-KIT-6, respectively.

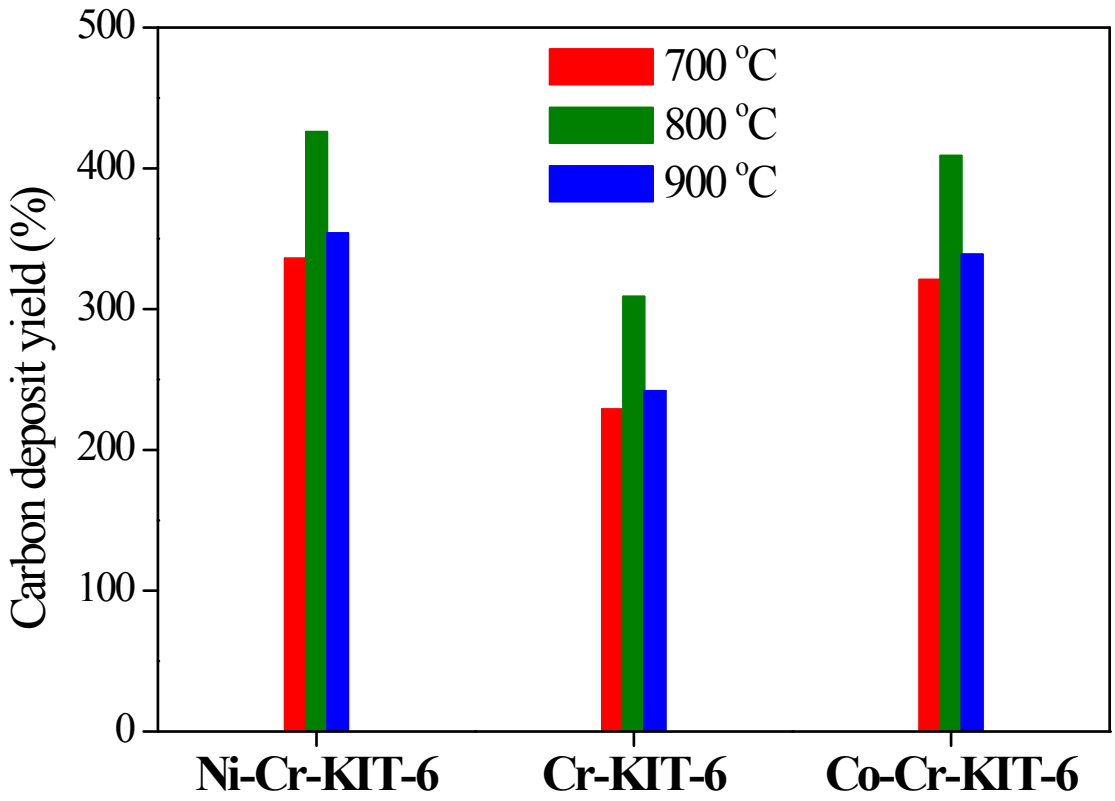

Fig. S5 Effect of reaction temperature on the amount of carbon deposited yield over Cr-KIT-6, Ni-Cr-KIT-6 and Co-Cr-KIT-6 mesoporous catalysts (Catalyst: 200 mg, acetylene: 50 sccm/min, argon: 100 sccm/min, hydrogen: 100 sccm/min and Reaction time: 30 min).

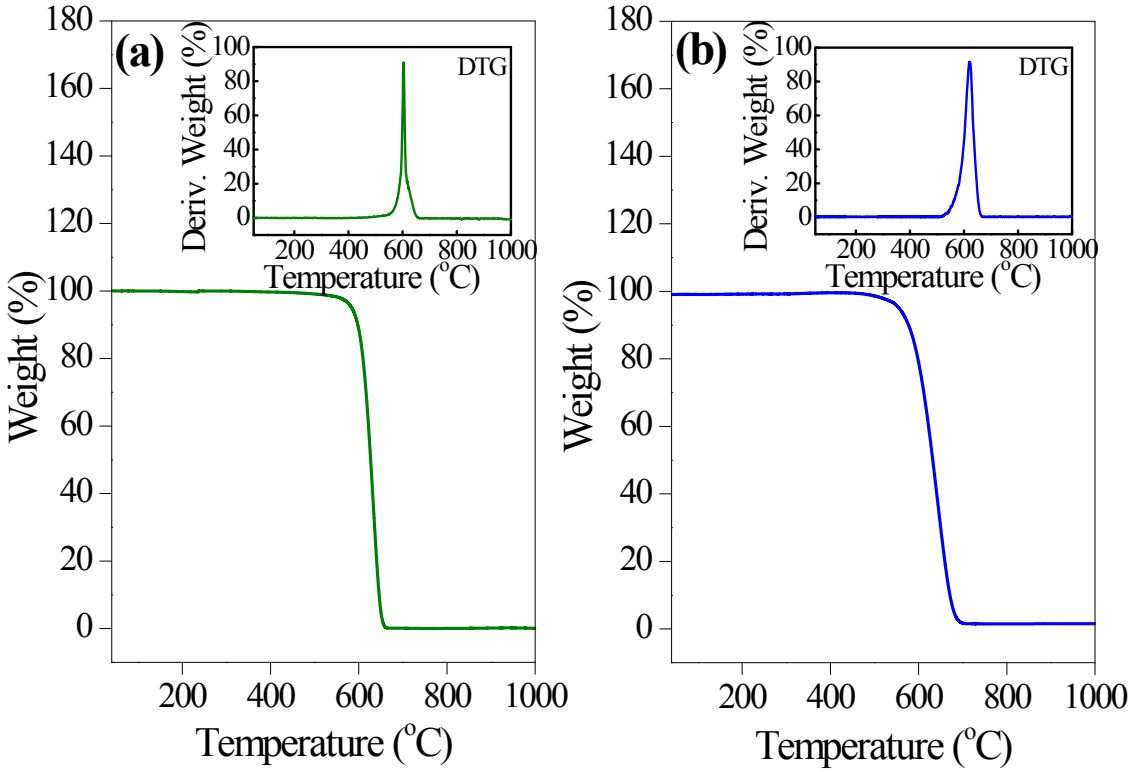

Fig. S6 TGA and DTG analysis of (a) MWCNTs (growth over Ni-Cr-KIT-6) and (b) MWCNTs (growth over Co-Cr-KIT-6).

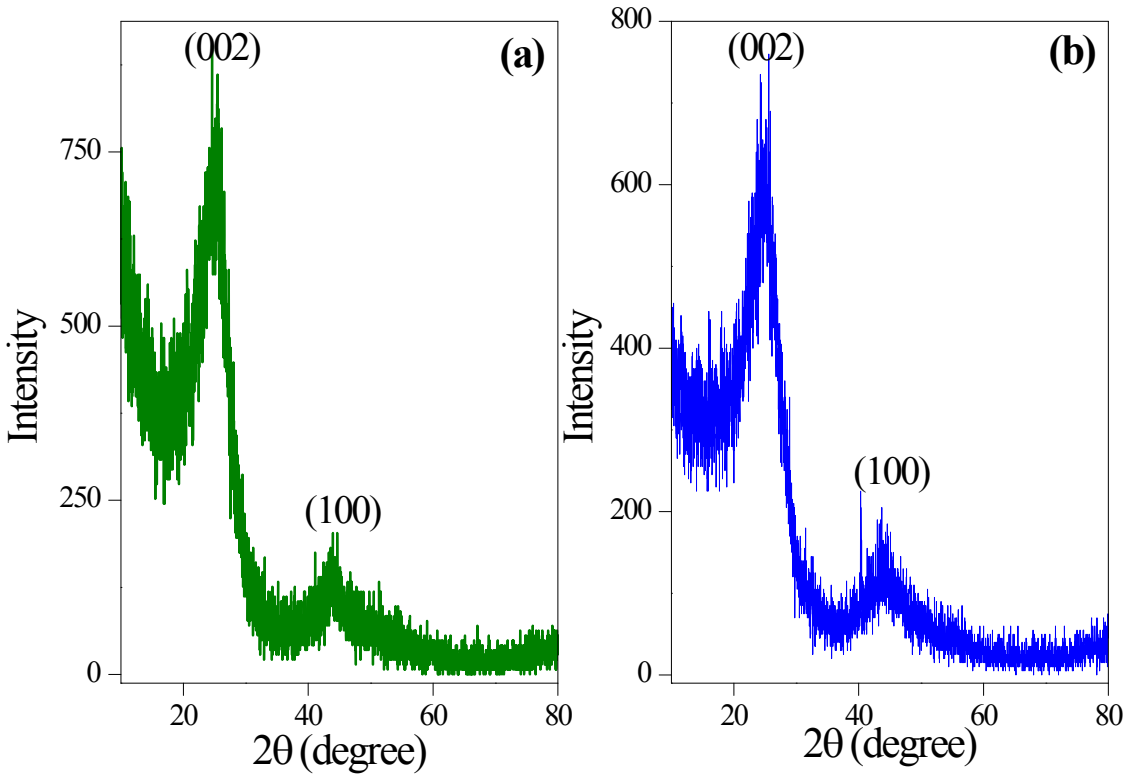

Fig. S7 XRD pattern of (a) MWCNTs (growth over Ni-Cr-KIT-6) and (b) MWCNTs (growth over Co-Cr-KIT-6).

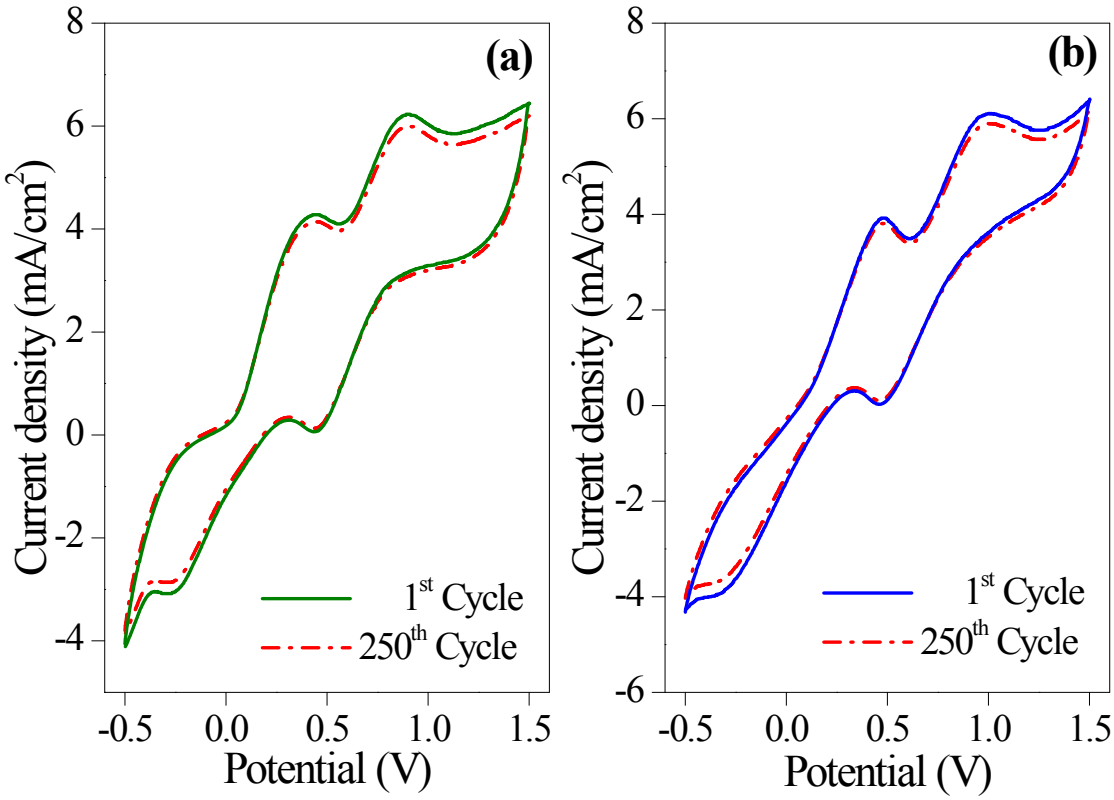

Fig. S8 250 consecutive cyclic voltammograms of (a) MWCNTs (growth over Ni-Cr-KIT-6) and (b) MWCNTs growth over Co-Cr-KIT-6) electrode in acetonitrile solution containing 10 mM LiI +1 mM I_2 + 0.1 M $LiClO_4$ at Scan rate 25 mV/s.

Tables

Table S1 Structural and textural properties of mesoporous Cr-KIT-6, Ni-Cr-KIT-6 and Co-Cr-KIT-6 catalysts.

Catalysts	d-spacing (nm)[a]	Unit cell parameter a_o (nm)[a]	Surface area ($m^2 g^{-1}$)[b]	Pore size (nm)[b]	Pore volume (cc g^{-1})[b]	Si/M ratio[c] (gel)	Si/M ratio[d] (gel)
Cr-KIT-6	9.38	19.6	795	5.95	1.0783	50	50.6
Ni-Cr-KIT-6	9.34	19.2	789	5.84	1.0723	50	49.6
Co-Cr-KIT-6	9.41	19.7	791	5.89	1.0746	50	48.8

[a]The values are obtained from small-angle XRD pattern

[b]The values are obtained from N_2 adsorption-desorption isotherm analysis

[c]The values are calculated from the gel (M = Cr, Ni-Cr & Co-Cr)

[d]The values are obtained from ICP-AES analysis (M = Cr, Ni-Cr & Co-Cr)

Table S2 Influence of catalysts for the growth of MWCNTs at the reaction time of 30 min.

Catalysts	Carbon deposition (%)
Co-KIT-6 (25)	269.97
Co-KIT-6 (50)	308.88
Co-KIT-6 (75)	275.43
Co-KIT-6 (100)	209.76

Flow rate of C_2H_2: 50 sccm/min, argon: 100 sccm/min, hydrogen: 100 sccm/min and temperature: 800°C

Table S3 Influence of acetylene flow rate on the amount of carbon deposit yield over Ni-Cr-KIT-6 and Co-Cr-KIT-6 catalyst (Catalyst: 100 mg, Argon: 100 sccm/min, H_2: 100 sccm/min, reaction time: 30 min and temperature: 800 °C).

Catalyst	Flow rate of C_2H_2 (sccm/min)	Carbon deposition (%)	Catalyst	Flow rate of C_2H_2 (sccm/min)	Carbon deposition (%)
Ni-Cr-KIT-6	10	109.89	Co-Cr-KIT-6	10	116.74
	20	267.89		20	271.08
	30	341.97		30	328.71
	40	397.26		40	372.46
	50	426.05		50	408.96
	60	389.98		60	359.58
	70	374.19		70	342.90
	80	359.39		80	330.46

Notes and References

S1 J. Sun, Q. Kan, Z. Li, G. Yu, H. Liu, X. Yang, Q. Huo and J. Guan, *RSC Adv.*, 2014, **4**, 2310–2317.