†Electronic Supplementary Information (ESI)

Tunable luminescence from two dimensional BCNO nanophosphor for high-contrast cellular imaging

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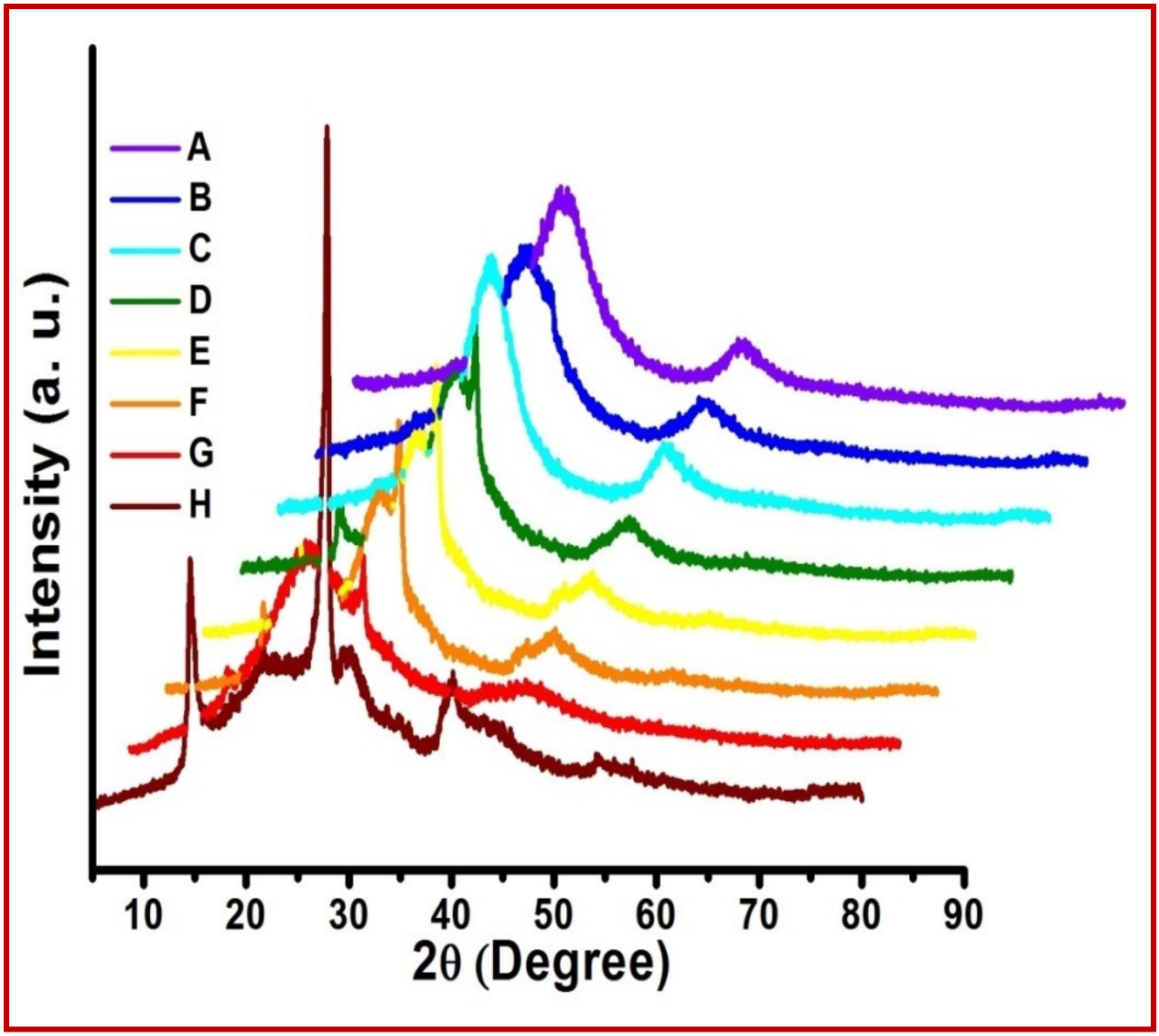

Figure S1: XRD patterns of as-synthesized samples A, B, C, D, E, F, G and H.

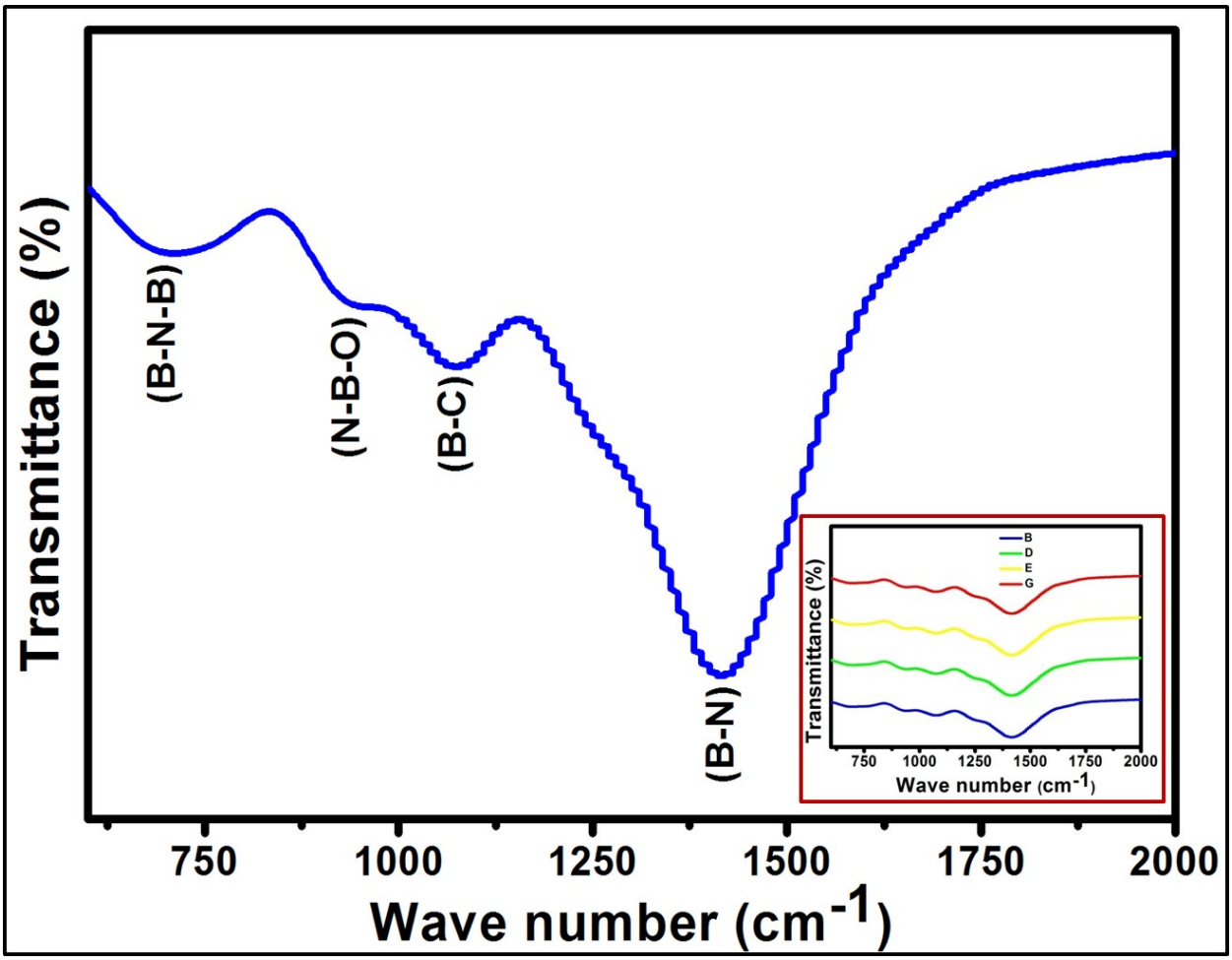

Figure S2: FTIR spectrum of sample B and inset shows the FTIR spectra of B, D, E and G samples having different amount of carbon content.

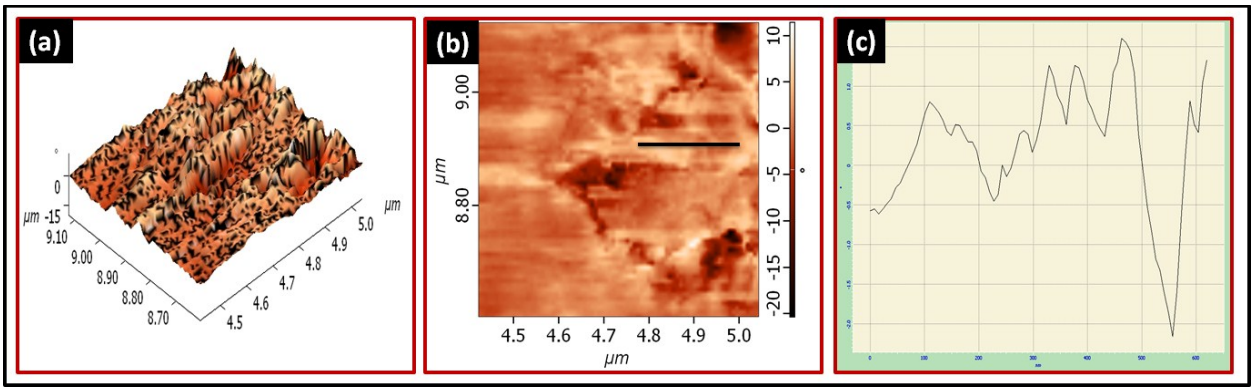

Figure S3: AFM image of 2D BCNO nanophosphor of sample G (a) exhibits 3D view of the 2D BCNO layer (b) represents the phase micrograph of 2D BCNO layer, the black mark represents the selected line from where the line-scan profile has been taken and (c) represents the line-scan profile of 2D BCNO layer which clearly shows the thickness around 2 nm with wrinkle surface that can also be seen in figures S3(a) and (b).

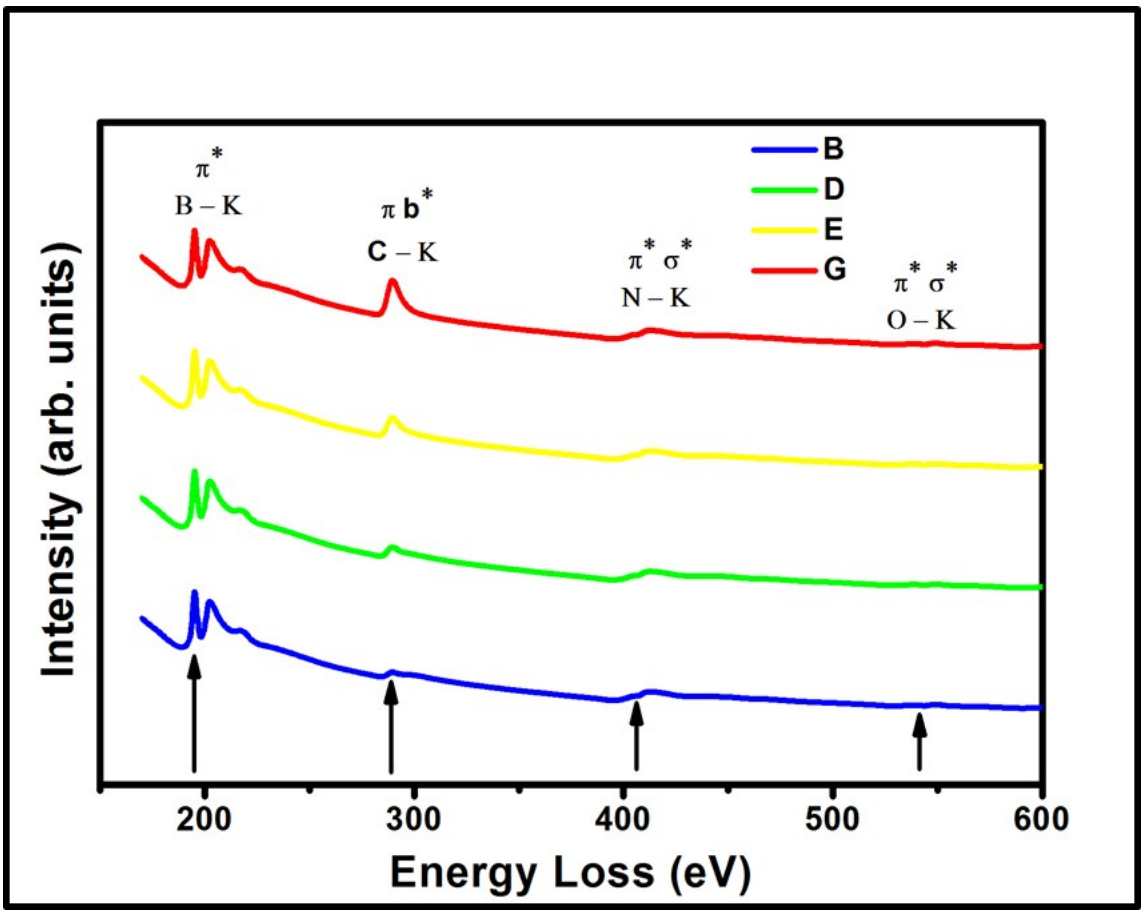

Figure S4: EELS spectra of B, D, E and G samples.

The EELS spectra of B, D, E and G exhibit two sharp peaks of B–K ionization at 193 and 201 eV for π* and σ* electrons, respectively. As Garvie et al. pointed out, in the case of a BCNO compound, if the B–K ionization for π* electrons has three peaks of 189.3, 192.1, and 194.1 eV, the B atom is surrounded by three elements, i.e., C, N, and O, respectively. Since the B–K ionization for π* electrons had only one peak between 192 and 194 eV, this meant that the B atom was intermediately surrounded by N and O atoms, which also implied that there were no clear B–C chemical bonds in the 2D BCNO nanophosphor. The peak at 285 eV is assigned to π* bands, while those at 288 and 295 eV are classified as σ* bands, in which the peak at 288 eV has C–H* features. Previous research showed that materials with weak sp2 hybrid orbitals, such as amorphous carbon, graphite, and solid benzene, can have a π* feature; while those having stronger sp3 hybridization[3], such as a diamond and solid cyclohexane, exhibit only σ* (including

C–H*) features with no π* bands. The C–H* feature can usually be found in organic materials, such as solid benzene and cyclohexane. In the present study, the C–H bonds are supposed to come from the organic residue of decomposed PEG. Since these data are evidence that the C atoms in the BCNO nanophosphor has π and σ bonds, they should have sp2 hybridization. The sp2 hybrids lie in a plane and are oriented toward the corners of an equilateral triangle at angles of 120 °C to one another and have a framework consisting mainly of a 6-membered carbon ring. Previously reported EELS data of C–K edges from different carbon sources supported the above hypothesis that the carbon in the BCNO compound has an amorphous structure with traces of C–H groups (organic residue). These should not have a sp3 structure that is rigid and hard, which can be obtained only under extreme conditions. In the present investigations, the BCNO compounds were prepared at low temperature (below 900°C and under ambient atmospheric conditions, resulting in a powder with a soft framework (sp2 hybridization). The ionization peak of N for the π* character is at 403.5 eV and the σ* character at 410.5 eV. Since the σ* peak intensity of N is higher than that of the π* peak, this means the major N atoms have σ* bonds with other elements. The ionization peak spectrum of O is also shown in Fig. S4, where the peaks at 537 and 545 eV are for the π* and σ* character, respectively. Basically, the BCNO phosphor is covalently bonded (with π* and σ* bonds) to the B and O atoms with a soft (sp2 hybridization) carbon lattice.

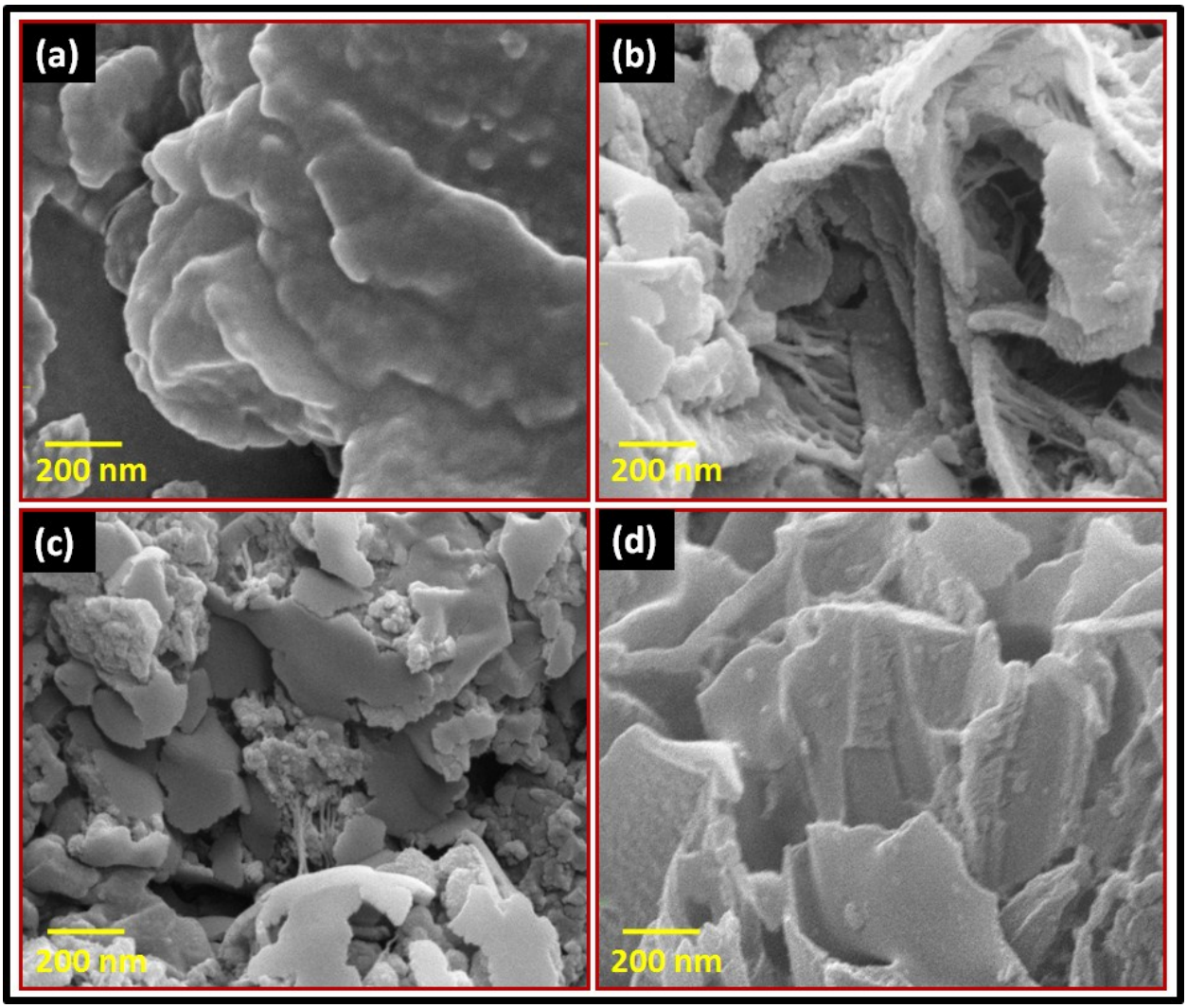

Figure S5: SEM images of (a) B, (b) D, (c) E and (d) G samples.

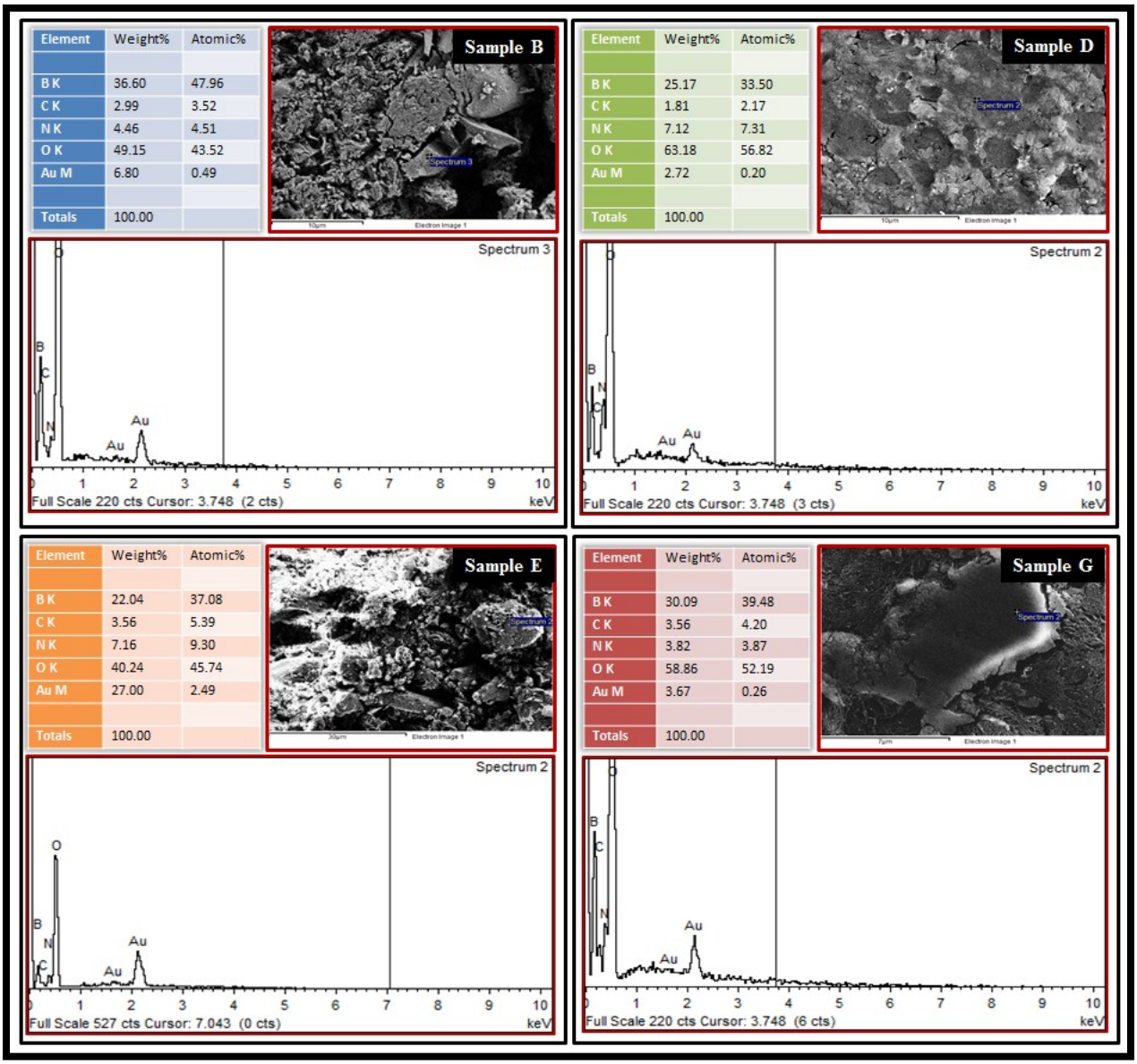

Figure S6: EDAX analysis of sample B, sample D, sample E and sample G .

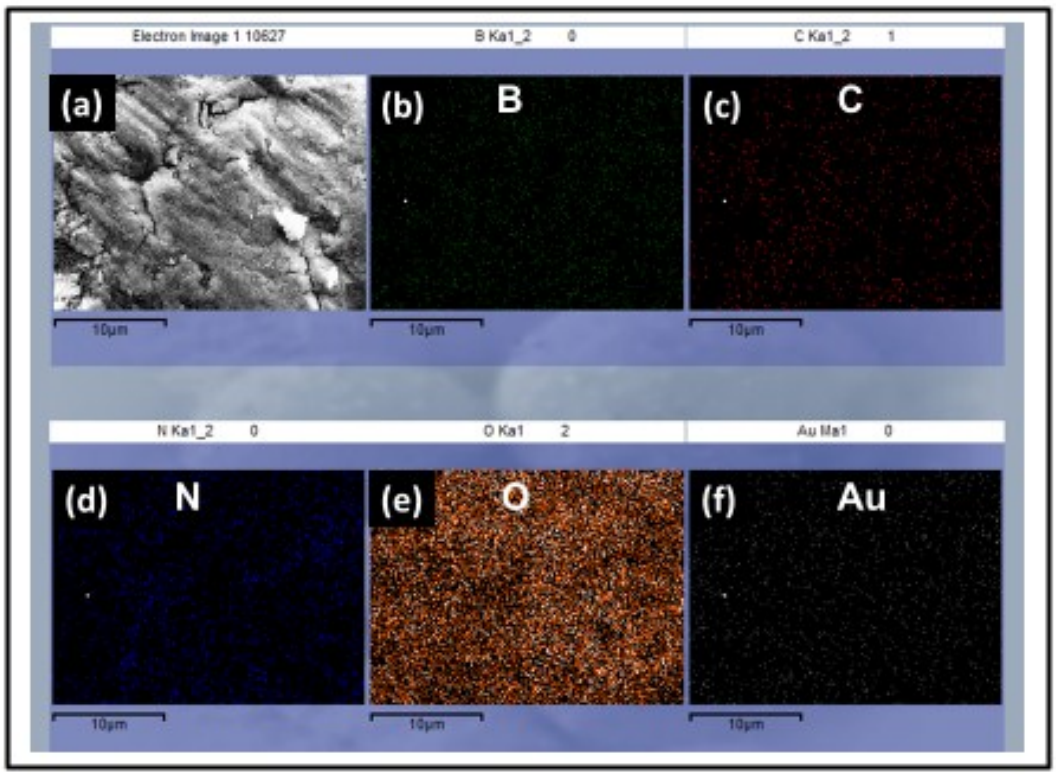

Figure S7: EDAX mapping of (a) represents the SEM image of selective area of mapping (b) B, (c) C, (d) N, (e) O and (f) Au elements.

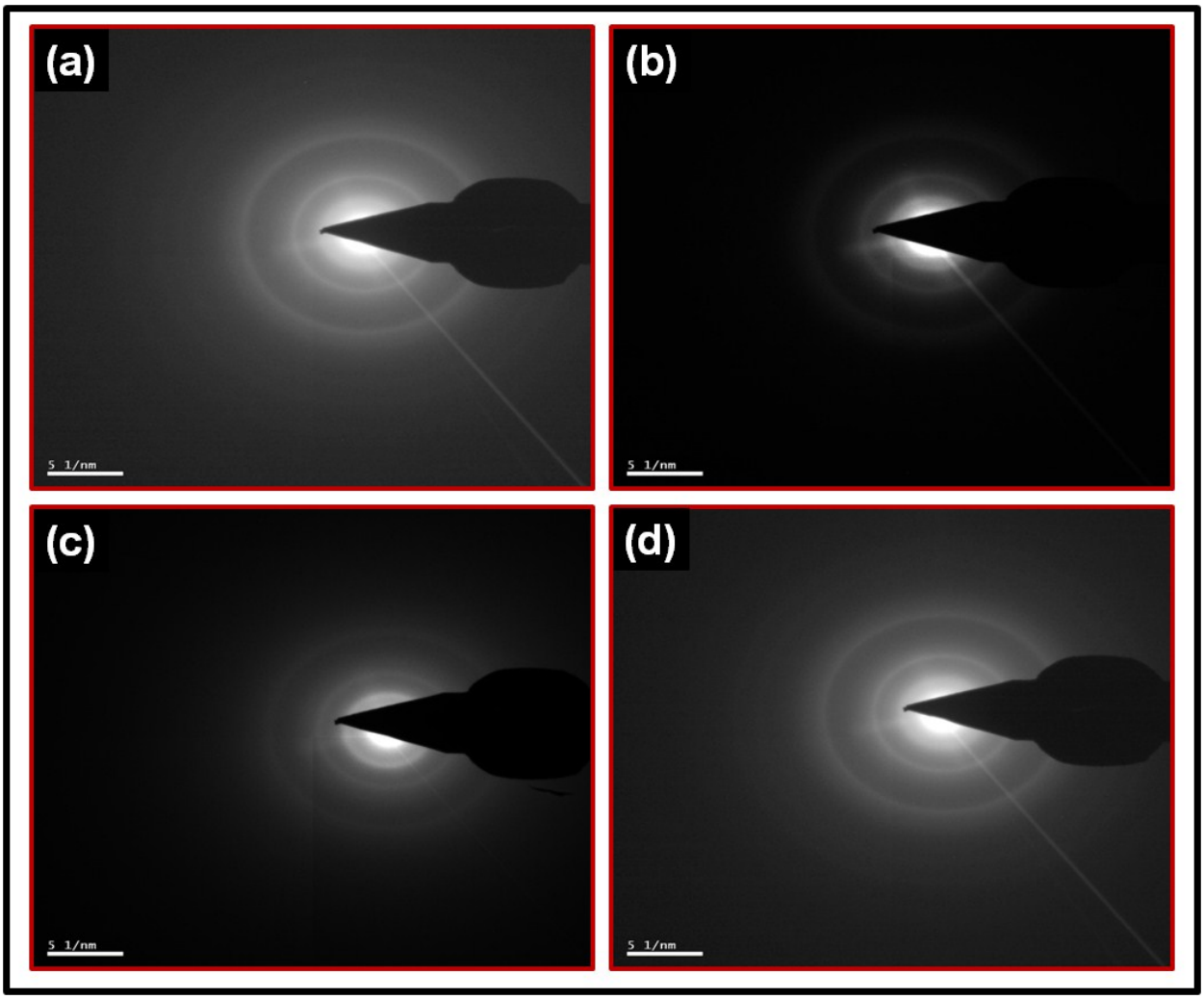

Figure S8: SAED pattern of (a) B, (b) D, (c) E and (d) G samples.

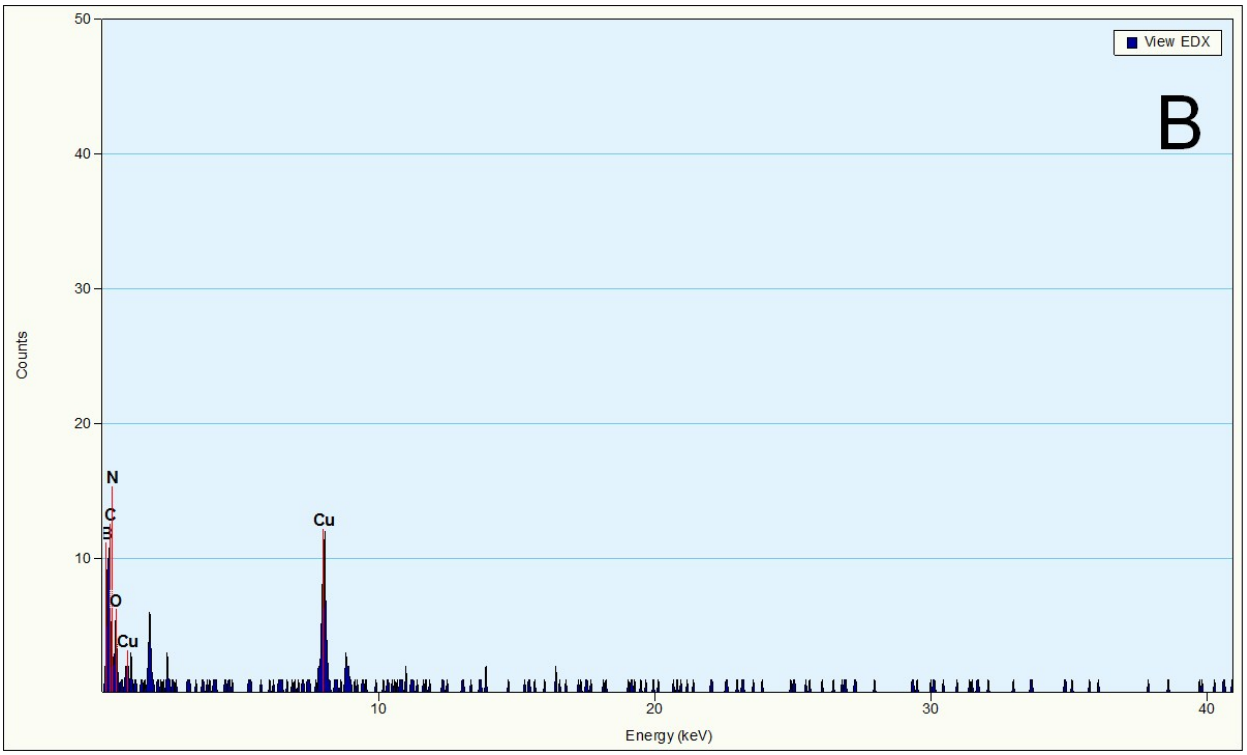

Figure S9: EDAX spectrum of sample B.

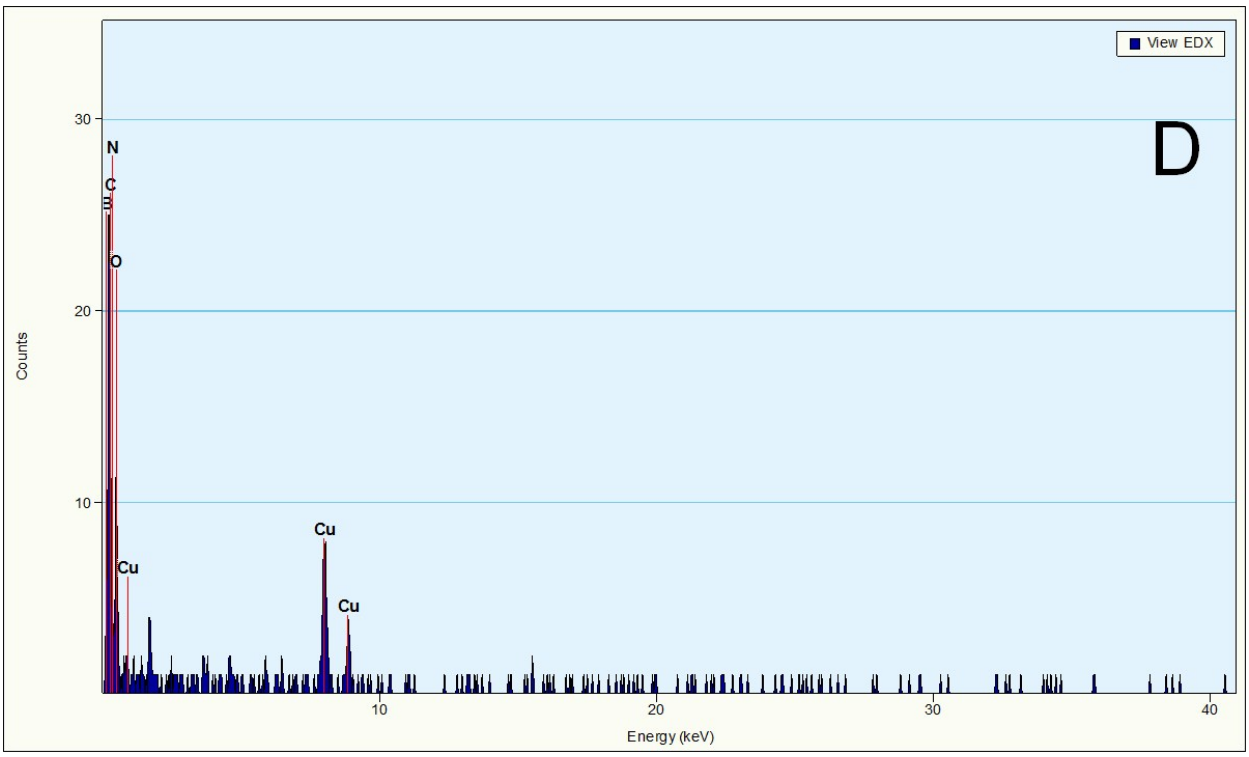

Figure S10: EDAX spectrum of sample D.

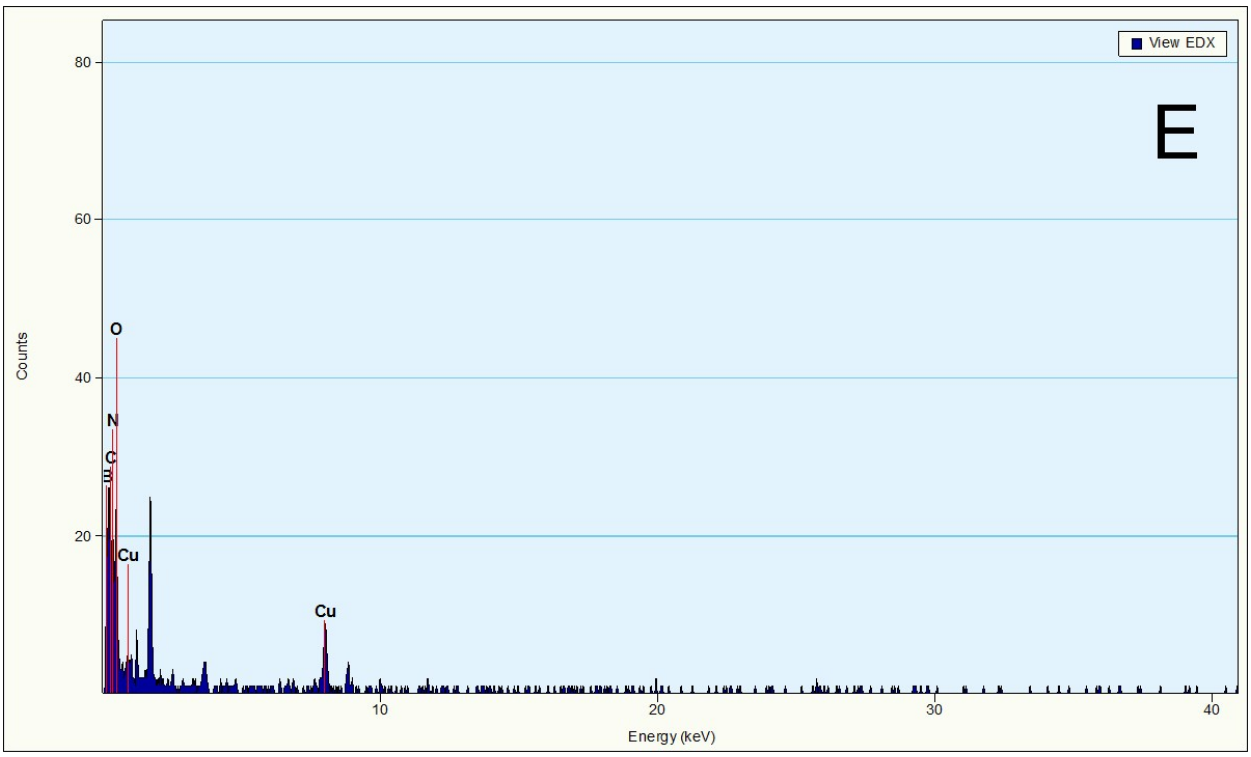

Figure S11: EDAX spectrum of sample E.

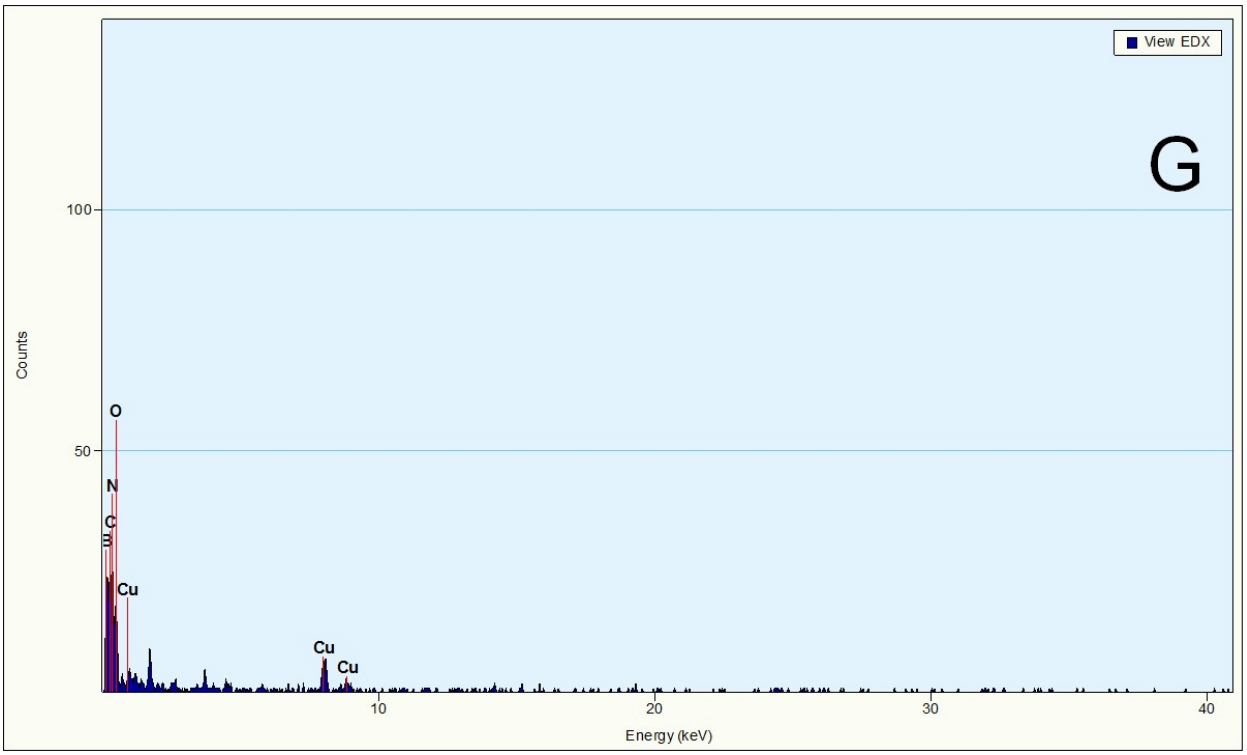

Figure S12: EDAX spectrum of sample G.

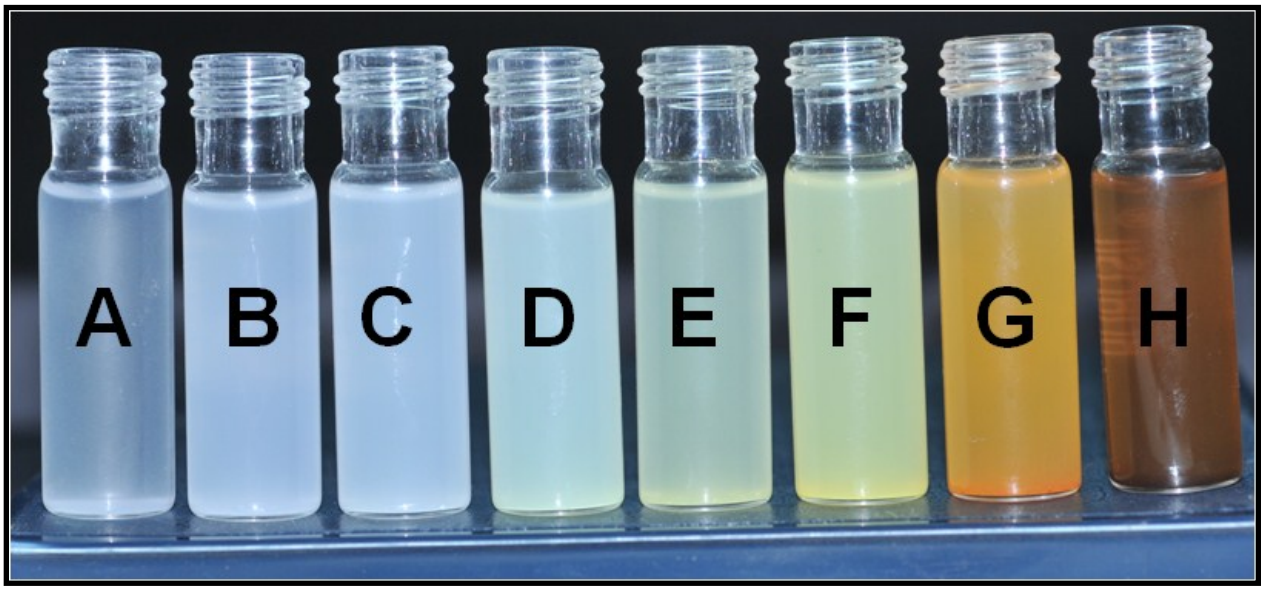

Figure S13: Samples A-H in water medium under room light.

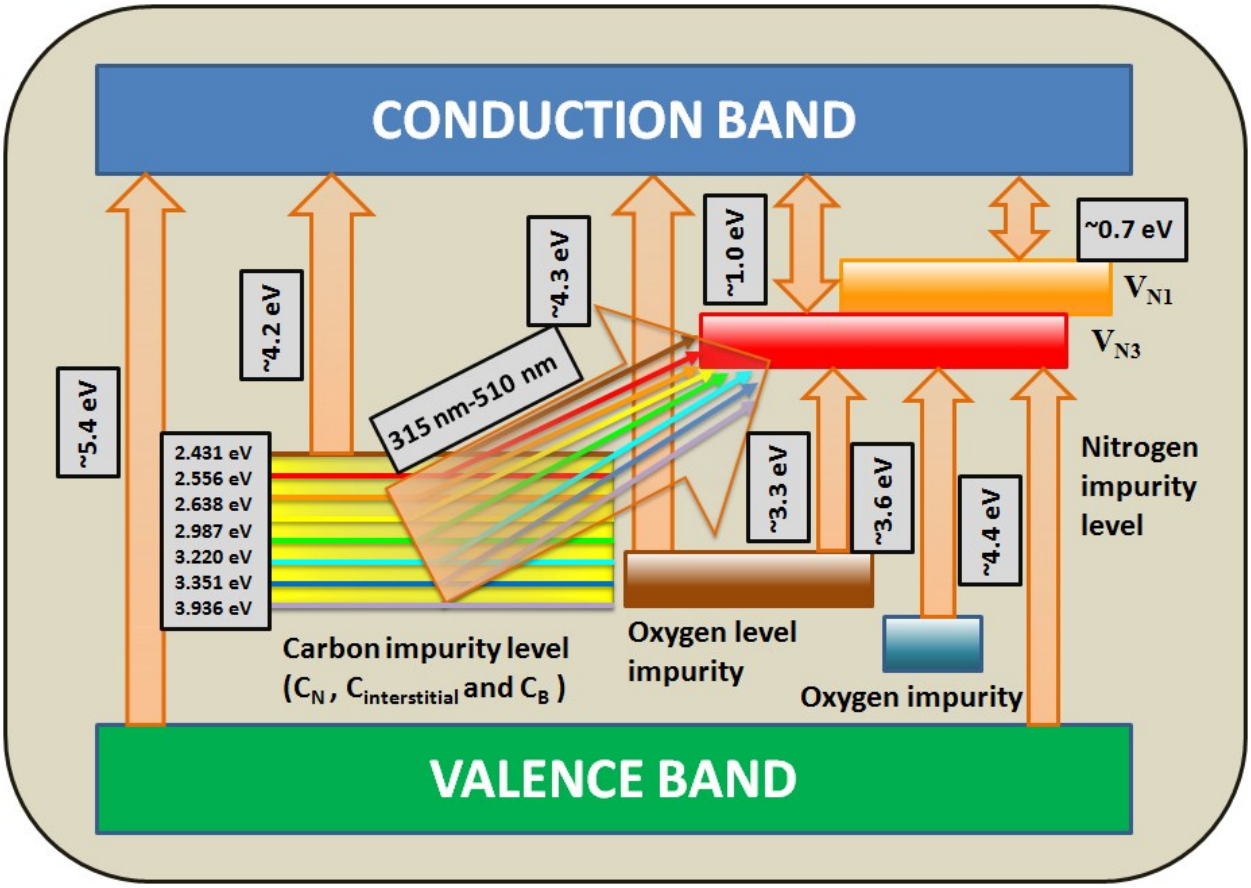

Figure S14: Proposed energy level diagram for multi-color transitions from BCNO layered structures.

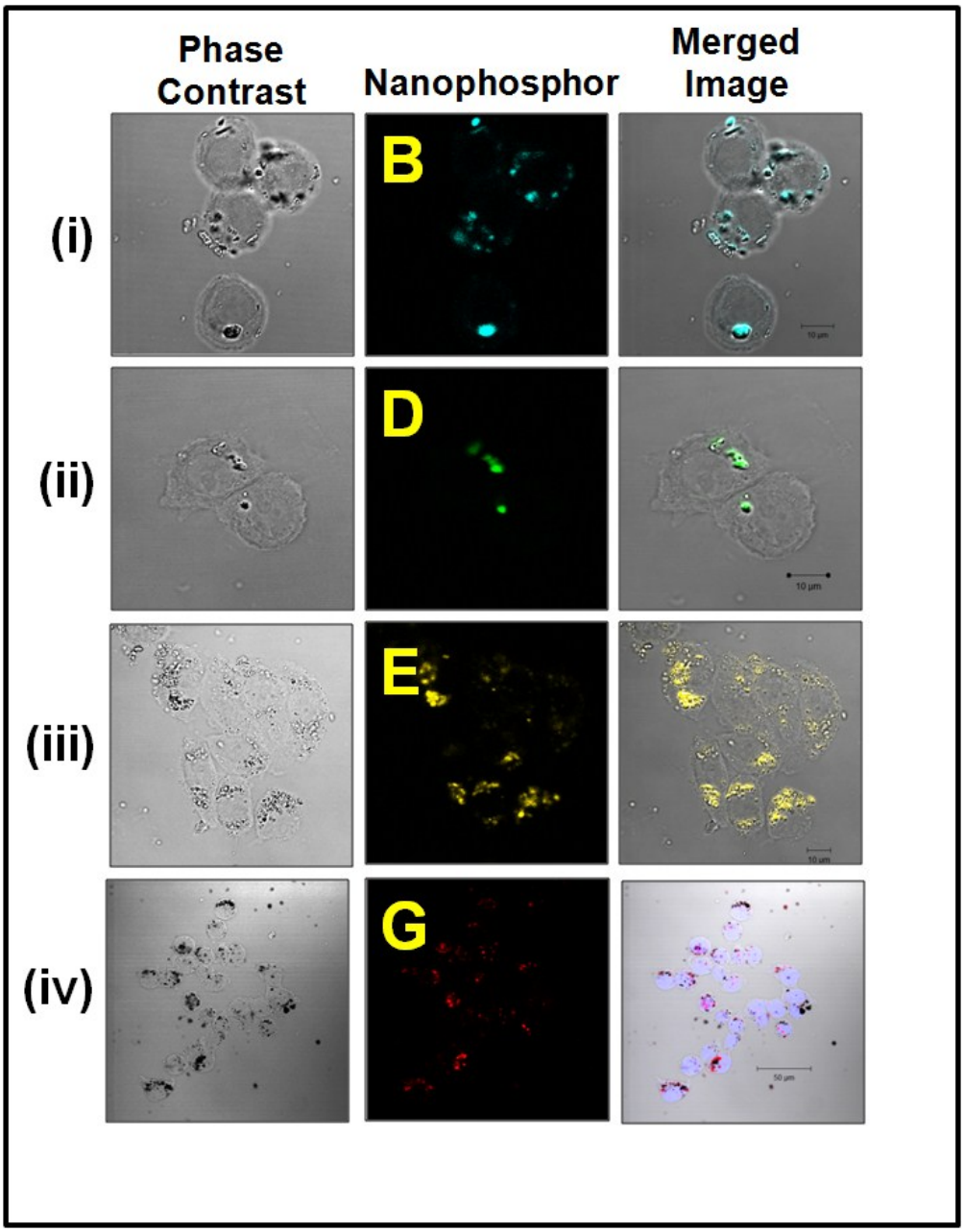

Figure S15: *In vitro* confocal microscopy images of HeLa cells incubated with 2D BCNO nanophosphor (25 μgmL^{-1}) for overnight. Sequential phase contrast, fluorescence and overlay images are shown for all the sample.(i) Sample B, with blue fluorescence (ii) Sample-D with green fluorescence (iii) Sample-E with yellow fluorescence (iv) Sample-G with red fluorescence are demonstrated. Sample G also stained with blue DAPI nucleus staining. Scale bars: 10μm.

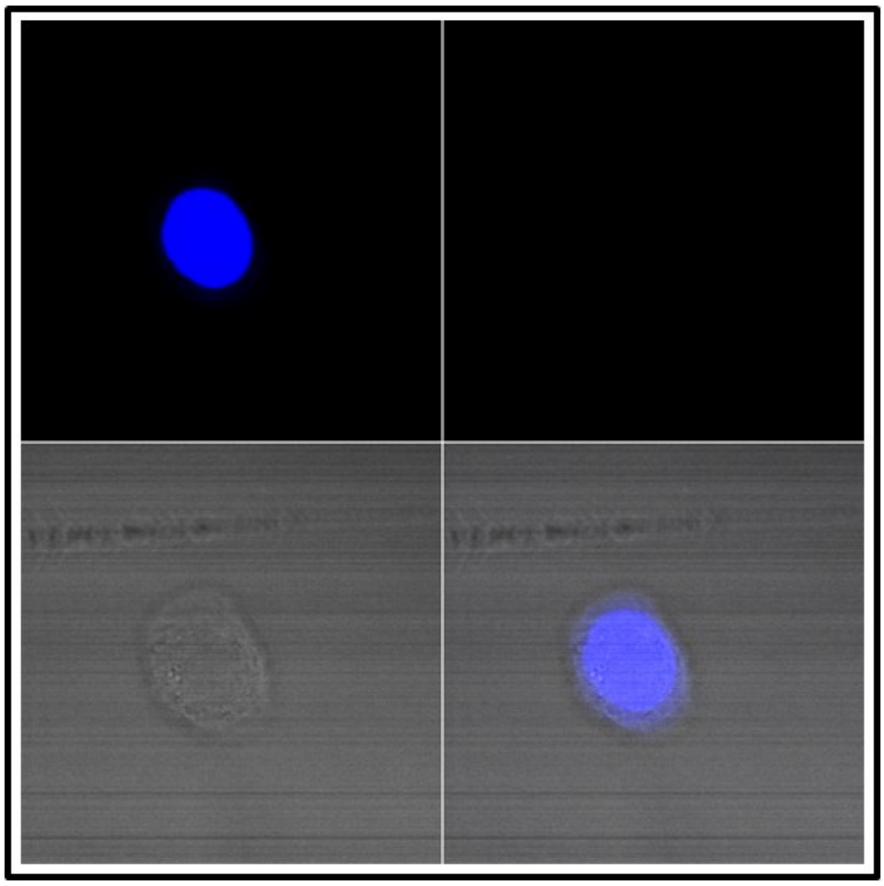

Figure S16: *In vitro* confocal microscopy images of HeLa cells incubated only with DAPI nuclear staining and without 2D BCNO nanophosphor. The images were photographed under similar microscopic conditions used for compound G.

Table T1: Summary of color emission at different ratios of B/C in 2D BCNO nanophosphor materials, where B/N ratio was kept constant.

Sample Name	B/N mol ratio	B/C mmol ratio	Emission Wavelength	Excitation Wavelength	Emission Wavelength	Quantum Efficiency
A	0.1	25/0	Violet	315 nm	342 nm	38%
B	0.1	25/0.05	Blue	370 nm	420 nm	45%
C	0.1	25/0.1	Sky blue	385 nm	485 nm	60%
D	0.1	25/0.15	Green	415 nm	515 nm	70%
E	0.1	25/0.2	Yellow	470 nm	580 nm	89%
F	0.1	25/0.2.5	Orange	478 nm	600 nm	72%
G	0.1	25/0.3	Red	485 nm	619 nm	63%
H	0.1	25/0.35	Deep red	510 nm	654 nm	21%

Table T2: Chromaticity co-ordinate (x,y) of the 2D BCNO nanophosphors (B, C, D, E, F, G and H samples) prepared with different B/C molar ratio.

B	Tristimulus	Chromaticity
X	122.392	0.1514
Y	100.000	0.1237
Z	585.932	0.7249
		1.0000

C	Tristimulus	Chromaticity
X	50.312	0.1766
Y	100.000	0.3511
Z	134.529	0.4723
		1.0000

D	Tristimulus	Chromaticity
X	64.273	0.2894
Y	100.000	0.4503
Z	57.786	0.2602
		1.0000

E	Tristimulus	Chromaticity
X	83.691	0.3689
Y	100.000	0.4408
Z	43.152	0.1902
		1.0000

F	Tristimulus	Chromaticity
X	128.735	0.5528
Y	100.000	0.4294
Z	4.146	0.0178
		1.0000

G	Tristimulus	Chromaticity
X	162.089	0.6168
Y	100.000	0.3805
Z	0.708	0.0027
		1.0000

H	Tristimulus	Chromaticity
X	143.317	0.5850
Y	100.000	0.4082
Z	1.690	0.0069
		1.0000

	X	Y
B	0.1514	0.1237
C	0.1766	0.3511
D	0.2894	0.4503
E	0.3689	0.4408
F	0.5528	0.4294
G	0.6168	0.3805
H	0.5850	0.4082

Table T3: Observed lifetimes for all the 2D BCNO nanophosphors (A, B, C, D, E, F, G and H powder samples) and their calculated average lifetime.

Sample	A_1	τ_1 (ns)	A_2	τ_2 (ns)	A_3	τ_3 (ns)	τ_{av} (ns)
A	0.95	1.62	0.02	6.83	0.03	3.19	2.016
B	0.9	1.60	0.04	5.77	0.06	2.60	2.212
C	0.86	1.51	0.09	5.24	0.05	2.36	2.494
D	0.96	1.53	0.03	5.34	0.01	2.36	1.911
E	0.83	1.82	0.08	5.90	0.09	2.62	2.773
F	0.78	1.21	0.12	4.77	0.1	2.58	2.557
G	0.93	1.38	0.05	5.28	0.02	2.76	2.069
H	0.81	1.85	0.07	6.69	0.12	3.21	3.036