Harnessing Nanostructured Materials to Achieve Superconductivity

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Introduction to superconductor

In 1911, **Kamerlingh Onnes** discovered that the resistivity of "pure" liquid helium dropped to zero at very low temperature, 4.2K (as shown in Figure 1). He also found that the resistive state is resorted in a magnetic field or a high transport currents. That is, superconductivity can be destroyed by an external magnetic field H_c which is also called the critical one.

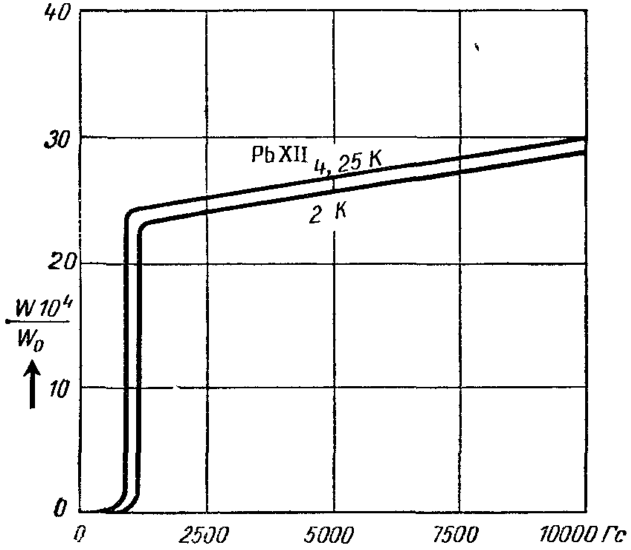


Figure 1. resistance vs. time

mun. Phys. Lab. Univ. Leiden, № 139 (1913), стр. 67, рис. 1].

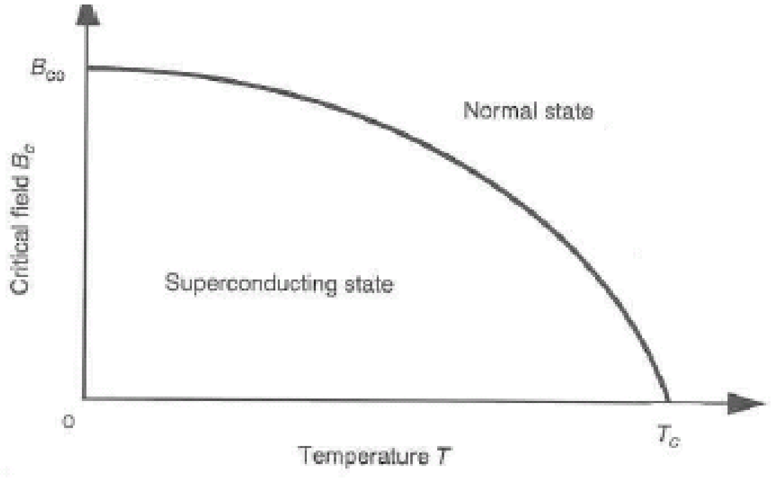


Figure 2: The critical magnetic field as a function of temperature

Applications of superconductor

There are many applications of superconductors. The major applications todate are below;

1. Meissner's effect, ie. when they are placed in a magnetic field, a superconductor has zero magnetic field inside it. Hence, the material is repelled by permanent magnets strongly and "perfectly" by virtue of which it finds applications in all places wherever magnetic levitation is required.
Uses-**Maglev Trains**

2.**Ability to generate strong magnetic fields:** The negligible resistance of superconductors enables them to generate very strong magnetic fields.
Uses-**M.R.I. in medicine, N.M.R. spectroscopy**

3.**High Conductivity:** The father property of the previous one, the high conductivity of these materials finds many uses in **high speed computing, efficient electronic devices, filters for wireless communication base stations.**

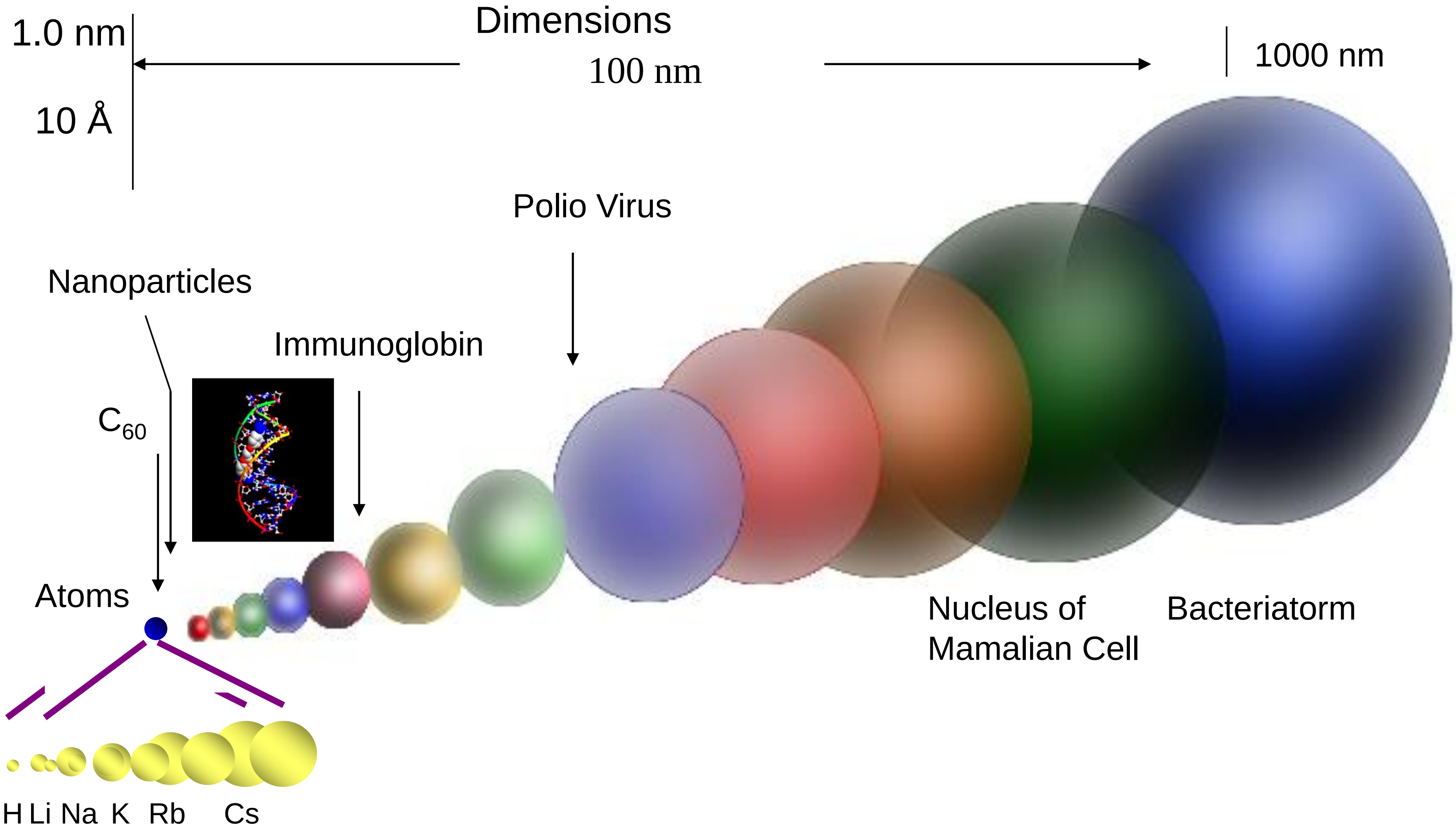
Motivations of our work

Yttrium barium copper oxide (YBCO) show high-temperature superconductivity (HTS) which brought significant breakthroughs in electric power technology, medicine, information technology, and many others.

For decades, scientist and engineers have been taking great efforts to develop **thin/ultra-thin superconductors** at high temperature which can achieve the high energy-saving and ultrahigh-speed processing. The most challenges to develop thin/ultra-thin HTS materials are related to identify the source of charge carrier, tailor the interface between different composites to enhance the current density, and, of course, an easy way to produce thin HTS materials.

Working with Saint Jean Carbon Inc. we demonstrate a simple process to incorporate superconductive nanoparticles onto graphene sheets, the two-dimensional structures at nanoscale. This work could offer an alternative method to produce ultra-thin HTS materials in an easy and controllable fashion.

➢ Scale from Micron to Nano



Dimensions

1.0 nm

10 Å

100 nm

1000 nm

Polio Virus

Nanoparticles

Immunoglobin

C_{60}

Atoms

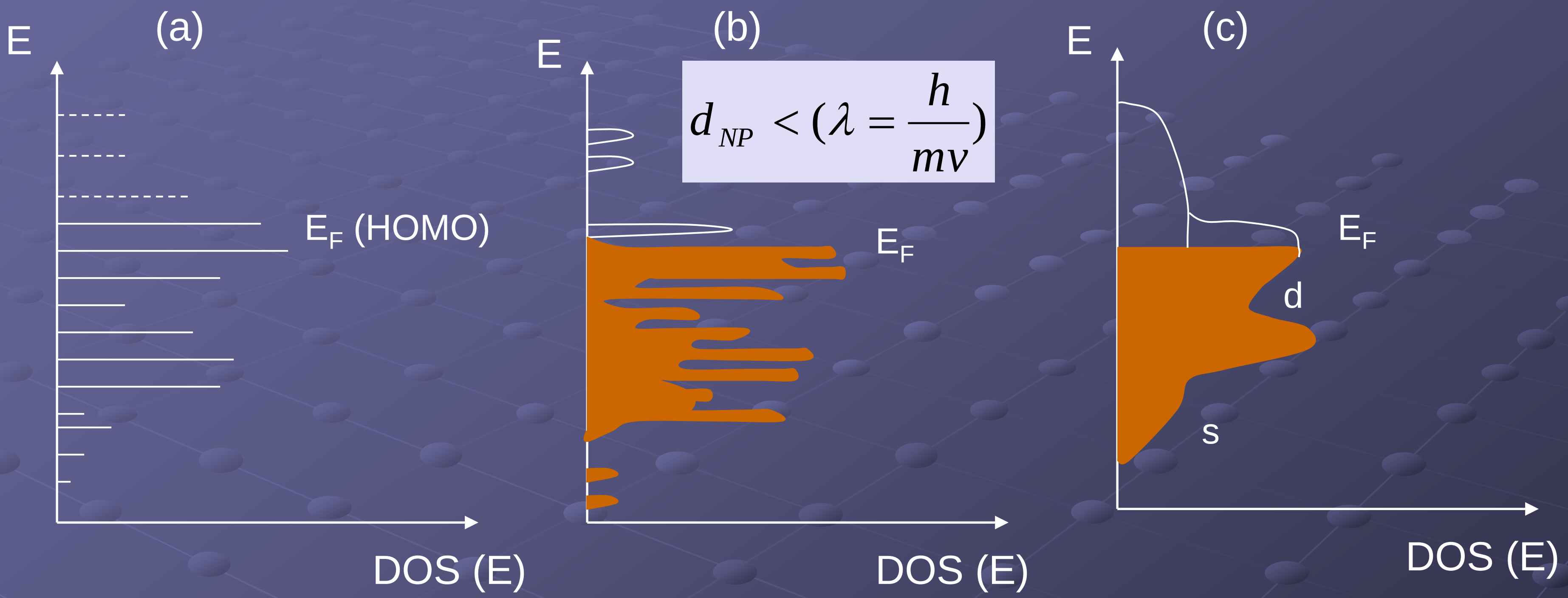
H Li Na K Rb Cs

Nucleus of
Mamalian Cell

Bacteriatorm

Dr. Jin Zhang

❖ Why are nanostructures interesting?



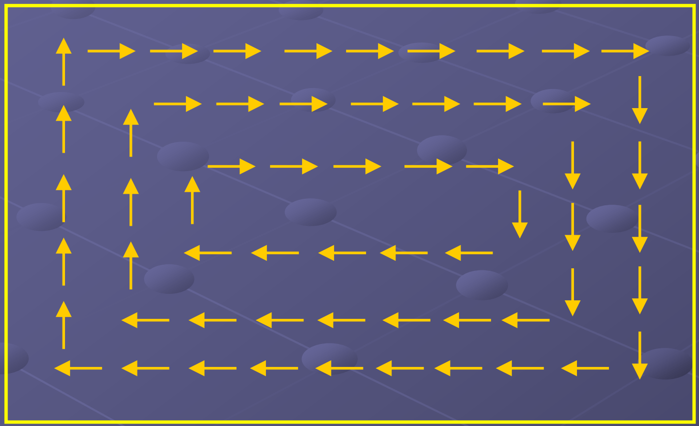
$$d_{NP} < (\lambda = \frac{h}{mv})$$

Scheme 1. Formation of a band structure (a) from a molecular state, (b) from a nanosized particle with broadened energy states, and (c) the fully developed band structure consisting of s and d band. E_F=Fermi energy; DOS=density of states. In (a) E_F corresponds to the highest occupied molecular orbital (HOMO).

Magnetic nanostructures

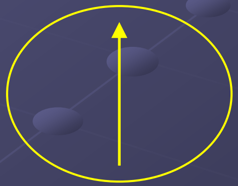
Bulk Ferromagnet

A ferromagneticly ordered crystal has a magnetic domain structure. This minimises the dipole energy.



Magnetic Nanoparticles

- Single domain particle
- Uniform magnetisation
- Coherent motion of magnetic moments



Two dimensional nanomaterials

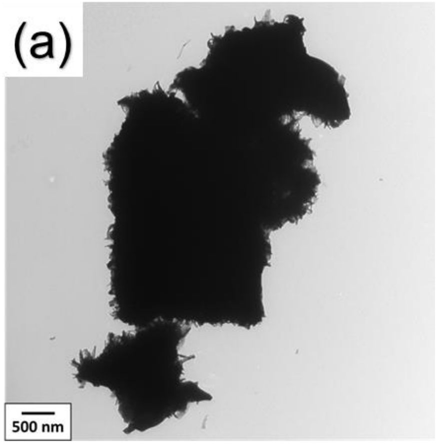
Two-dimensional materials, also known as 2D materials, normally have single atomic layer. This unique structure makes 2D materials, the lightweight materials, gain various superior physical and chemical properties.

Graphene is a typical 2D carbon nanomaterials which offers remarkable mechanical, electrical, thermal, and optical properties. Many synthesis processes have been developed to produce graphene nanosheets at lab and in factory.

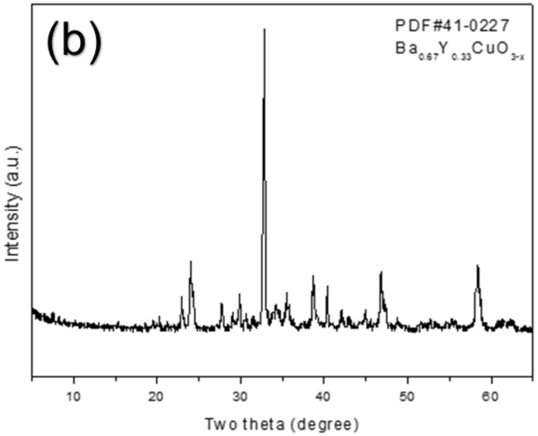
Properties	Graphene	Other materials
Room-temperature electron mobility ($cm^2\ V^{-1}\ s^{-1}$)	2.5×10^5 (Graphene)[1]	1.0×10^5 (Carbon nanotube)[2]
Thermal conductivity ($W\ mK^{-1}$)	$> 3.0 \times 10^3$ (Graphene)[3]	0.4×10^3 (Silver)[4]
Young’s modulus (GPa)	1.0×10^3 (Graphene)[5]	$1.0 \times 10^3 – 1.2 \times 10^3$ (Diamond)[6]
Ultimate tensile strength (MPa)	1.3×10^5 (Graphene)[5]	9.6×10^3 (Carbon nanotube film)[7]

Cite: [1] *A.S. Mayorov, et al. , Nano Lett. 11 (2011) 2396-2399.*
[2] *T. Dürkop, et al. , Nano Lett. 4 (2004) 35-39.*
[3] *K.M.F. Shahil, et al. , Nano Lett. 12 (2012) 861-867*
[4] *H.D. Young, et al. , Addison-Wesley Pub. Co., Reading, Mass., 1992.*
[5] *C. Lee, et al. , Science 321 (2008) 385-388.*
[6] *K.E. Spear, et al. , John Wiley & Sons, 1994.*
[7] *W. Xu, et al. , Nano Lett. 16 (2016) 946-952.*

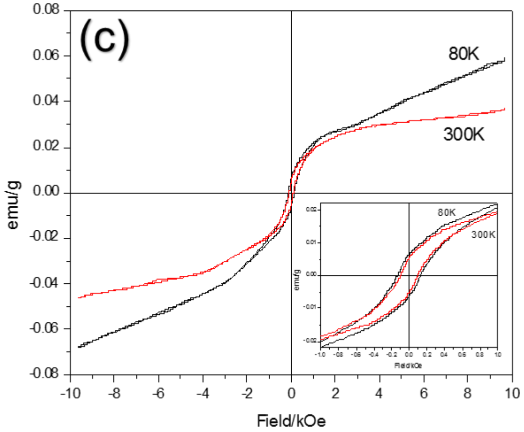
Characterization of YBCO particles and YBCO/graphene hybrid nanocomposites



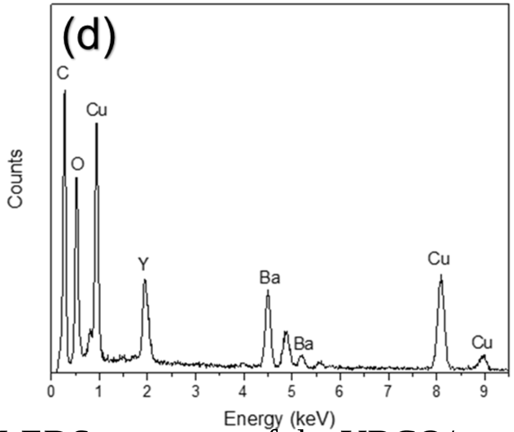
TEM micrograph of original YBCO particles



XRD spectrum of as-purchased YBCO powder



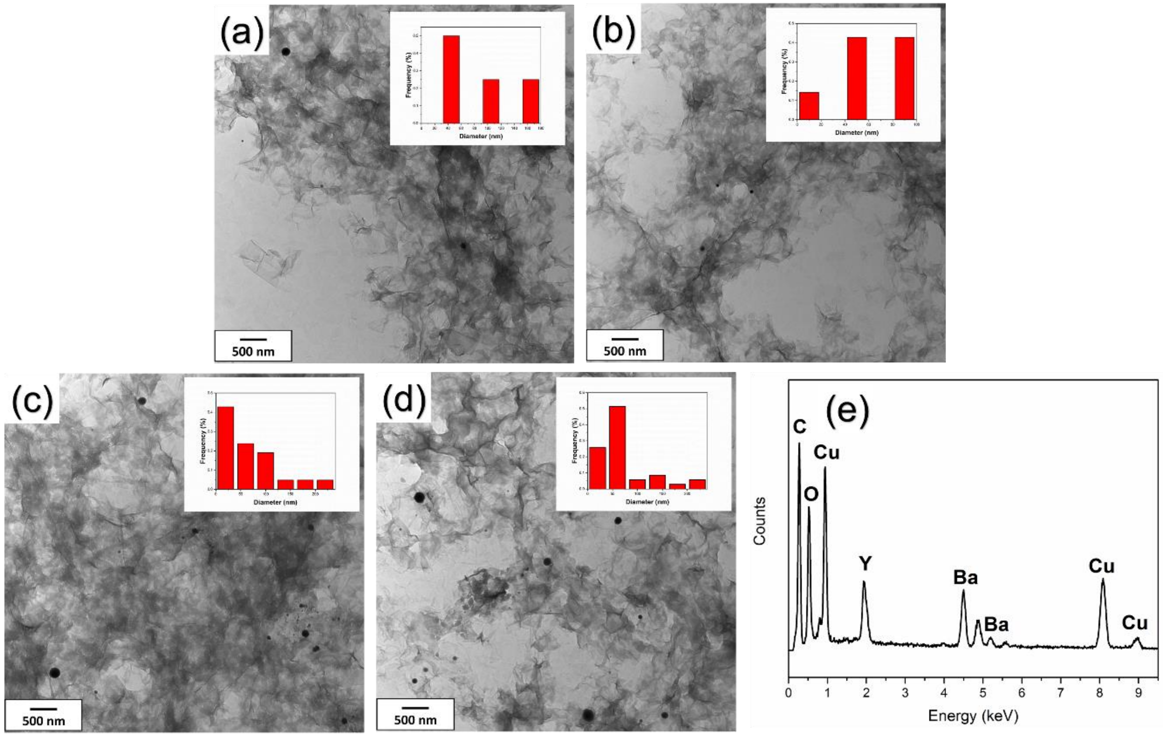
The magnetic properties of YBCO powder



TEM-EDS spectrum of the YBCO/graphene hybrid nanocomposites[12]

Cite: [12] *C.S. Lim, et al. , J. Mater. Chem. A 3 (2015) 8346-8352.*

Deposition of YBCO nanoparticles on Graphene sheets



TEM micrograph of the YBCO particles on the surface of the substrate under different deposition time (*t*) (a) *t* = 0.5 hr; (b) *t* = 1.0 hr; (c) *t* = 1.5 hr; (d) *t* = 2.0 hr; (e) TEM-EDX spectrum of the graphene/YBCO hybrid nanosheets (*t* =2.0 hr).