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Advances in tailoring the electronic properties of single-walled carbon nanotubes

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ABSTRACT

Considerable progress has been made in the last several years in the fields of investigation and understanding of the influence of encapsulated substances on the electronic properties of single-walled carbon nanotubes (SWCNTs). Relevant data on the modified electronic properties of filled SWCNTs were obtained. The possibility of achieving both acceptor and donor doping and precise changes of the SWCNT doping level by the filling of channels and transformation of incorporated substances was demonstrated. This article presents a comprehensive review of the current status of the research on the electronic properties of filled SWCNTs. The review begins with a brief description of basic aspects of the band theory of solids and peculiarities of the band structure and electronic properties of SWCNTs. The next part of the review is dedicated to a systematization and description of different methods for modification of the SWCNT electronic properties. Then, the review introduces filling methods of SWCNT inner channels. The main part of the review is dedicated to an analysis, systematization and generalization of the up-to-date reported results on experimental and theoretical investigations of the electronic properties of filled SWCNTs and nanostructures obtained as result of chemical reactions inside the SWCNT channels. Finally, the possible applications of filled nanotubes are highlighted.

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Nomenclature

Acronyms

AFM	atomic force microscopy
BWF	Breit–Wigner–Fano function
CVD	chemical vapor deposition
DFT	density functional theory
DMF	dimethylformamide
DNBN	3,5-dinitrobenzonitrile
DOS	density of states
DWCNT	double-walled carbon nanotube
EC charging	electrochemical charging
EELS	electron energy loss spectroscopy
F_4TCNQ	tetrafluorocyano-*p*-quinodimethane
FWHM	full width at half maximum
HRTEM	high-resolution transmission electron microscopy
LO phonon	longitudinal optical phonon
MRI	magnetic resonance imaging
NIR	near-infrared
NT	nanotube
OAS	optical absorption spectroscopy
PLS	photoluminescence spectroscopy
QM	quantum-chemical modeling
RBM	radial breathing mode
RS	Raman spectroscopy
STS	scanning tunneling spectroscopy
SWCNT	single-walled carbon nanotube
TCNQ	tetracyano-*p*-quinodimethane
TDAE	tetrakis(dimethylamino)ethylene
TEM	transmission electron microscopy
TMTSF	tetramethyl-tetraselenefulvalene
TO phonon	transversal optical phonon
TTF	tetrathiafulvalene
UPS	ultraviolet photoelectron spectroscopy
UV	ultraviolet
vHs	van Hove singularities
WF	work function
XAS	X-ray absorption spectroscopy
XES	X-ray emission spectroscopy
XPS	X-ray photoelectron spectroscopy
X@SWCNT	single-walled carbon nanotube filled with substance X
1D	one-dimensional

Symbols

$\mathbf{a_1}$, $\mathbf{a_2}$, $\mathbf{a_3}$	basis vectors of the direct lattice
a	lattice parameter of a graphene layer
a_{c-c}	the nearest-neighbor carbon–carbon distance in a graphene layer
$\mathbf{b_1}$, $\mathbf{b_2}$, $\mathbf{b_3}$	basis vectors of the reciprocal lattice
$\mathbf{C_h}$	chiral vector of a nanotube
d	the highest common divisor of chirality indexes n and m of a nanotube
d_R	the greatest common divisor of $2m + n$ and $2n + m$
d_t	diameter of nanotube
$D(E)$	density of states
$D(E_F)$	density of states at the Fermi energy