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One-dimensional nitrogen-containing carbon nanostructures

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A B S T R A C T

One-dimensional nitrogen-containing carbon nanostructures (1-D NCNSs) have emerged in the past two decades as exceptionally promising nanomaterials due to their unique physical and chemical properties which enable a broad range of applications in various fields of modern technology. Recent investigations revealed that the 1-D NCNS-based materials can have a profound impact on energy conversion and storage, catalysis and electrocatalysis, sensors, electronic nanodevices, environmental protection, and biology-related applications. The aim of the present review article was to provide a comprehensive overview of scientific progress in 1-D NCNSs such as N-containing carbon nanotubes (NCNTs, e.g., single-walled (SWNCNTs), double-walled (DWNCNTs), and multi-walled NCNTs (MWNCNTs)), nanofibers (NCNFs), nanowires (NCNWs), nanorods (NCNRs), and nanohorns (NCNHs), and evaluate their future perspective. Various methods of preparation of 1-D NCNSs and their composites are summarized and discussed. The structure–properties relations of 1-D NCNSs, based on the theoretical approach and numerous relevant physico-chemical methods of characterization, were outlined. The emphasis is given to the properties of 1-D NCNSs rendered by nitrogen incorporation into the carbon matrix in order to provide deeper insight into the specific characteristics which determine materials' performances within the specific fields of applications.

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Abbreviations and symbols

0-D	zero-dimensional
1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
Ag	silver
Al	aluminum
Al_2O_3	aluminum(III) oxide (alumina)
Ar	argon
at.%	atomic percent
Au	gold
B	boron
BNCNF(s)	boron/nitrogen-containing carbon nanofiber(s)
BNCNT(s)	boron/nitrogen-containing carbon nanotube(s)
Br	bromine
C	carbon
Cd	cadmium
CeO_2	cerium(IV) oxide
CH_3CN	acetonitrile
CH_4	methane
C_2H_2	acetylene
C_3N_4	carbon nitride
CNF(s)	carbon nanofiber(s)
CNH(s)	carbon nanohorn(s)
CNS(s)	carbon nanostructure(s)
CNT(s)	carbon nanotube(s)
CNT-COOH(s)	oxidized carbon nanotube(s)
CNW(s)	carbon nanowire(s)
CN_x	nitrogen-containing carbon
Co	cobalt
CO	carbon monoxide
CO_2	carbon dioxide
CoO	cobalt(II) oxide
Cu	copper
$CuSO_4$	copper(II) sulfate
CVD	chemical vapor deposition
DAFC(s)	direct alcohol fuel cell(s)
DFT	density functional theory
DMFC(s)	direct methanol fuel cell(s)
DNA	deoxyribonucleic acid
DSSC(s)	dye-sensitized solar cell(s)
DWNCNT(s)	double-walled nitrogen-containing carbon nanotube(s)
ECR	electron cyclotron resonance
EDL	electrical double layer
EELS	electron energy-loss spectroscopy
EIS	electrochemical impedance spectroscopy
ER	electrorheological
F	fluorine
FE	field emission
Fe	iron
Fe_2O_3	iron(III) oxide
Fe_3O_4	iron(II,III) oxide
FET(s)	field-effect transistors