Synthesis of carbon nanomaterials by thermal plasma: a brief review

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Abstract

The current production of carbon nanomaterials is facing the following two challenges: high selectivity toward specific chemical compositions or morphologies and their scalable production. Thermal plasma technology rises as an alternative method to produce carbonaceous materials. Thermal plasmas promote extreme process conditions which allow the conversion of any organic carbon precursor: liquid, solid, or gaseous to valuable nanostructures, which can range from carbon black, carbon nanotubes, graphene, and fullerenes, with high product selectivity.

Introduction

The scientific and technological progress in several areas observed since the early 20th century has led to a wide variety of studies related to carbon nanomaterials due to the demand from industries for new technological solutions [1].

Carbon nanotubes (CNT) and graphene are materials with great perspectives for the achievement of innovations in the various areas of interest of carbon nanotechnology and related materials, due to their unique properties and the possibility of producing from renewable feedstock.

Among the technologies used for the synthesis of carbon nanomaterials, Thermal Plasma Technology (TPT) has attracted significant attention and development as they provide advantages regarding the nanomaterials produced. However, to the best of our knowledge, the influence of the most important variables on the process of achieving carbon nanomaterials by thermal plasma has not been previously discussed. Also, this brief review must be pointed out the advantages and limitations of the process and highlight characteristics process (e. g, plasma generation; processing parameters; carbon precursor (feedstock)); and the properties of the carbon nanomaterial of each process.

Table. 1. Different types of carbon nanomaterials produced from thermal plasma processing.

Carbon nanomaterial	Type of thermal plasma	Processing parameters	Feedstock	Catalytic metal
CB	DC plasma	-	Polymers	-
	AC plasma	(~50-100 kW)	CH_4, C_2H_4, C_8H_8, PFO	-
	DC plasma	(~90-200 kW)	CH_4	-
	DC-RF hybrid plasma	(14 kW RF/7 kW DC)	CH_4	-
	RF plasma	(10 kW, 20.7 and 89.6 kPa)	CH_4	-
Fullerene	RF plasma	(1.67 MHz, 30 kW, 10-20 kPa)	Carbon powder	-
	RF plasma	(40 kW, 66 kPa)	CBs	Ni
	RF plasma	(30 kW, 101 kPa)	Graphite powder	-
	DC-RF hybrid plasma	(4 MHz, 20 kW RF/5 kW DC, 35-101 kPa)	Carbon powder	-
CNT	Microwave plasma	(2.45 GHz, 1300 W, 101 kPa)	C_2H_4	$C_{10}H_{10}Fe$
	DC plasma	(14.4 kW, 66 kPa)	CH_4	Ni
	DC plasma	(100-300 A, 3 kV)	CO	C_5FeO_5
	RF plasma	(3 MHz, 40 kW, 66 kPa)	CB	Ni, Co, CeO_2, Y2O3
	RF plasma	(2-5 MHz, 47 kW, 66 kPa)	C_7H_8	$C_{10}H_{10}Fe + C_4H_4S$
Graphene	DC plasma	(48 kW, 101 kPa)	CH_4	-
	DC plasma	(600 kW)	C_2H_6O	-
	RF plasma	(~3 MHz, 20 kW, 55.2 and 89.6 kPa)	CH_4	-

Thermal Plasma Technology (TPT)

Plasma is a partially or fully ionized gas containing electrons, ions, and neutral particles (atoms, molecules, radicals) [2]. Plasmas can be classified mainly according to the ionization degree and temperature [3]. High-temperature plasmas and low-temperature plasmas. However, low-temperature plasmas can still be divided into thermal and non-thermal plasmas. Where for thermal plasmas, the electrons temperature can be slightly higher or equal to temperature of the heavy particles, non-thermal plasmas show a big discrepancy between electron and ion temperature.

The subject of the present review paper is limited to thermal plasma and its application in the synthesis of carbon nanomaterials.

Synthesis of carbon nanomaterials

Several methods by thermal plasma process have been developed for the synthesis of carbon nanomaterials in the literature, discussing plasma properties responsible for the nanomaterial growth with high throughput, high purity, anisotropy, desired compositions, or narrow size distributions. These properties can vary according to four categories: type of thermal plasma generates, plasma conditions, type feedstock (carbon precursor), and type and dispersion of catalysts (Transition metals - e.g., Fe, Ni, Co, Mo). The main differences in the synthesis of carbon nanomaterials by thermal plasma according to the four categories above are summarized in Table 1.

Conclusion

This brief review has been built relating only to carbon nanomaterials synthesis techniques by thermal plasma. Still necessary to expand the work to review in detail all processes reported in the literature.

References

[1] K.S. Kim, T.H. Kim, Nanofabrication by thermal plasma jets: From nanoparticles to low-dimensional nanomaterials, J. Appl. Phys.

[2] M. Capitelli et al., Fundamental Aspects of Plasma Chemical Physics: Kinetics, 2015.

[3] U. Schumacher, Basics of Plasma Physics, Plasma Phys. (2005)