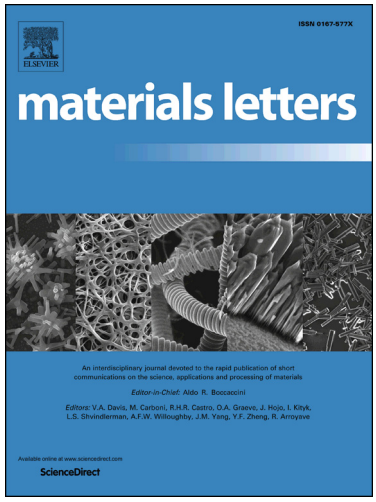

An easy route to synthesis high-quality black phosphorus from amorphous red phosphorus

G. Tiouitchi, M. Ait Ali, A. Benyoussef, M. Hamedoun, A. Lachgar, M. Benaissa, A. Kara, A. Ennaoui, A. Mahmoud, F. Boschini, H. Oughaddou, A. El Kenz, O. Mounkachi

PII: S0167-577X(18)31581-7
DOI: https://doi.org/10.1016/j.matlet.2018.10.019
Reference: MLBLUE 25060

To appear in: *Materials Letters*

Received Date: 22 August 2018
Revised Date: 27 September 2018
Accepted Date: 5 October 2018

Please cite this article as: G. Tiouitchi, M.A. Ali, A. Benyoussef, M. Hamedoun, A. Lachgar, M. Benaissa, A. Kara, A. Ennaoui, A. Mahmoud, F. Boschini, H. Oughaddou, A. El Kenz, O. Mounkachi, An easy route to synthesis high-quality black phosphorus from amorphous red phosphorus, *Materials Letters* (2018), doi: https://doi.org/10.1016/j.matlet.2018.10.019

An easy route to synthesis high-quality black phosphorus from amorphous red phosphorus

G.Tiouitchi [a,b], M. Ait Ali[c] , A. Benyoussef [a,b,d] , M. Hamedoun [a], A. Lachgar[e] , M. Benaissa [a], A. Kara[f], A. Ennaoui[g], A. Mahmoud[h], F. Boschini[h], H. Oughaddou[i,j] , A. El Kenz [a], and O. Mounkachi [a,*]

[a] Laboratory of Condensed Matter and Interdisciplinary Sciences (LaMCScI) , B.P. 1014, Faculty of Science-Mohammed V University, Rabat, Morocco.

[b]Materials and Nanomaterials Center, MAScIR Foundation, Rabat Design Center Rue Mohamed Al Jazouli, Madinat Al Irfane , Rabat 10 100 , Morocco.

[c]Coordination Chemistry Laboratory, Cadi Ayyad University, Faculty of sciences Semlalia (UCA-FSSM), B.P. 2390 - 40000 Marrakech, Morocco.

[d]Hassan II Academy of Science and Technology, Rabat, Morocco

[e]Department of Chemistry, Wake Forest University, Winston-Salem, North Carolina United States.

[f]Department of Physics, University of Central Florida, Orlando, Florida 32816, United States.

[g]Institut de recherche en energie solaire et energies nouvelles, Morocco

[h]GREENMAT, CESAM, Institute of Chemistry B6, University of Liege, 4000 Liège, Belgium.

[i]Institut des Sciences Moléculaires d'Orsay, ISMO-CNRS, Bât. 210, Université Paris-Sud, 91405 Orsay, France.

[j]Département de Physique, Université de Cergy-Pontoise, 95031 Cergy-Pontoise Cedex, France.

Abstract

The development of an easy and efficient process for producing black phosphorus (BP) remains a bottleneck for the use of BP in large-scale applications. In this work, we present a simple, potentially scalable, and economically viable method for the preparation of high-quality BP from amorphous red phosphorus. BP was synthesized under low pressure and temperature conditions from red phosphorus via the addition of small quantities of copper, tin, and tin(IV) iodide. Characterization by powder X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive spectrometry (EDX), high-resolution transmission electron microscopy (HR-TEM), and Raman spectroscopy were performed to confirm the high quality and purity of the formed BP.

Keywords: Amorphous red phosphorus, Black phosphorus, HR-TEM, Raman spectroscopy, XRD, SEM, EDX.

E-mail: o.mounkachi@gmail.com , kachiomar@gmail.com

Introduction

Black phosphorus (BP) was first discovered by Percy William Bridgman in 1914 from white phosphorus under high pressure conditions (~ 1.2-1.3 GPa, 200 °C)[1]. Phosphorus has four main allotropes[2]. The most popular of these allotropes are red, white, and black [3,4]. Red and white phosphorus are highly flammable unlike BP which is the most stable of the allotropes. BP forms with several crystalline structures including orthorhombic, rhombohedral, and cubic[5,6]. Nevertlhese, the orthorhombic black phosphorus with space group Cmce[7,8] is an important material because of its layered structure [9]. BP presents as a very promising raw material for the electronics and energy markets, due to its high charge mobility and a direct gap of the order of 0.3 to 1.5 eV, depending on its thickness[10,11]. These characteristics can be used for the design of optoelectronic, photonic and optics