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Abstract
In this study, the synthesis of poly [N-9′-heptadecanyl-2, 7-carbazole-alt-5, 5-(4′, 7′-di-2-thienyl-2′, 1′, 3′-benzothiadiazole)] (PCDTBT) nanotubes via a templating method is reported. PCDTBT nanotubes were successfully grown by immersing the porous alumina template into 15 mg/ml of solution concentration for 2- and 24-h periods and annealed at 50°C. Changes in morphological and optical properties between nanotubes of different infiltration times (2 and 24 h) as well as its thin films are observed. The longer infiltration time of 24 h produced nanotubes with enhanced morphological, structural, and optical properties. Nanotubes that are formed between 2 and 24 h of infiltration show enhancement in absorption, photoluminescence, and shift in Raman peak if compared to their thin films.

Keywords: PCDTBT; Nanotubes; Porous alumina template; Infiltration

Background
Conjugated polymers have been widely used in a number of technologies such as organic light emitting diodes, organic photovoltaics devices and sensors due to their favorable properties [1-4]. Optimizing the performance of such devices is rather complex due to the molecular nature of the polymer. Fabricating one-dimensional nanostructure such as nanorods, nanowires and nanotubes into the devices can enhance the photon absorption, electron transportation, and electron collection [5]. Template-assisted method is one of the simplest and cost effective methods that have been extensively used in the fabrication of polymer nanostructures [6-8]. A templating method has a great potential to produce various one-dimensional nanostructures with different favorable properties. The optical, electronic properties and polymer chain packing of the nanostructures can be altered by changing the templating technique and parameters such as varying the annealing temperature, infiltration time, spin coating rate, polymer concentration and type of solvents [8-11].

Poly [N-9′-heptadecanyl-2, 7-carbazole-alt-5, 5-(4′, 7′-di-2-thienyl-2′, 1′, 3′-benzothiadiazole)] (PCDTBT) is a promising p-type conjugated polymer that possesses exceptional electrical conductivity and optical properties [4,7,10,12-15]. These exceptional properties have attracted many researchers to utilize the PCDTBT thin film as an active layer in organic photovoltaic devices [10,12,13]. However, to the authors’ best knowledge, no studies are available in the literature on modification of PCDTBT thin films into nanostructures. Desired PCDTBT nanostructures can be altered by controlling the infiltration time of template wetting. Characterization studies on the impact of varying the infiltration time of template wetting could provide further understanding on the growth mechanism of polymeric nanostructures. In this paper, PCDTBT nanotubes that have been prepared via template wetting are reported. These nanotubes were obtained by immersing the porous alumina template in 15 mg/ml of PCDTBT solution of two different infiltration times (2 and 24 h), prior to annealing at 50°C. This study examines the improvements in morphological, structural, and optical properties of PCDTBT nanotubes compared to their thin film counterparts.

Methods
The commercially available PCDTBT from Luminescence Technology Corp (Taiwan, ROC) was used without further purification. The 15 mg/ml of PCDTBT solution concentration was prepared in chloroform. A template
in the Raman shift were recorded by the PCDTBT nanotubes and thin films. However, a downward and upward shift occurred at the band of C-C stretching of the DTBT unit for PCDTBT nanotubes [4]. No changes in the Raman shift were observed between the PCDTBT nanotubes and thin films for the broad DTBT ring stretch located at 1,460 and 1,554 cm\(^{-1}\) [4].

Conclusions
In this work, PCDTBT nanotubes have been synthesized by using a template wetting of a porous alumina template. Infiltration time and wetting behavior have shown to play a significant role in controlling the properties of PCDTBT nanotubes. The longer immersion time produced PCDTBT nanotubes that have more enhanced morphological, structural, and optical properties over their thin films.

Abbreviations
FESEM: field emission scanning electron microscopy; HRTEM: high resolution transmission electron microscopy; NaOH: sodium hydroxide; PCDTBT: poly[N-9′-heptadecanyl-2,7-carbazole-alt-5,5-(4′,7′-di-2-thienyl-2′,1′,3′-benzothiadiazole)]; PL: photoluminescence.

Competing interests
The authors declare that they have no competing interests.

Authors’ contributions
NAB carried out the experiment, participated in the sequence alignment, and drafted the manuscript. AS participated in the design of the study, performed the analysis, and helped draft the manuscript. KS conceived of and drafted the manuscript. AS and KS are senior lecturers at the Department of Physics, University of Malaya. AS’s and NAB is currently doing his Ph.D. at the University of Malaya. AS and KS are investigators.

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NAB is currently doing his Ph.D. at the University of Malaya. AS and KS are senior lecturers at the Department of Physics, University of Malaya. AS’s and NAB’s research interests include the synthesis of nanostructured materials via template-assisted method and applications in organic electronic devices such as sensors and photovoltaic cells.

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