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Wood-based straightway channel structure for high performance microwave absorption

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ABSTRACT

Microwave absorption (MA) materials have gained wide range of applications including satellite communications, radar detections, etc. Here, for the first time we designed high-performance porous biomass-pyrolized carbon (PBPC) based on natural wood. The PBPC with orderly parallel channel structure is on the top among all MA materials, showing excellent MA performance with maximum reflection loss (RL) of −68.3 dB and absorption bandwidth (RL ≤ -10 dB) up to 7.63 GHz. Furthermore, we predict the reflection loss by calculation and point out regulation of electrical conductivity would maximize MA performance. The combination of renewability, easy mass production and simple fabrication provides PBPC practical application value, and the strategy of channel structure design followed by permittivity adjustment casts a light for accessing new high-performance MA materials.

1. Introduction

Electromagnetic pollution becomes nonnegligible to human activity, and microwave absorbing materials are becoming indispensable in civil and military fields [1]. Conventional magnetic material like ferrite shows good microwave absorption (MA) performance through magnetic loss ability [2,3]. However, ferrites are always limited by high filling ratio and heaviness. In addition, magnetic nanofillers mainly contribute to absorption in low-frequency ranges, and few exhibit high permeability above 10 GHz [4]. Newly developed carbon materials including carbon nanotube (CNT) and graphene are considered promising in MA due to their high specific surface area and low density [1], so carbon-based foams, carbon-polymer composites and carbon-ferrite composites were fabricated to realize high MA performance [5–8]. However, most of the porous carbon MA materials are irregular in their microstructure, the random structure may result in excessive reflection at the interface, thereby reducing the MA capability. Hence, designing novel carbon-based MA materials with regularly aligned micropores is of significance.

Comparing with the artificial materials with irregular structure, some natural materials like wood, shows highly ordered microstructure. Wood is ubiquitously used as a structural material across the globe [9]. Its renewability, easy mass production and simple processing methods make it valuable to prepare high-performance materials. Recently, materials based on wood-extracted cellulose nanocrystals and cellulose nanofibers were designed, showing excellent optical and mechanical properties [10]. Additionally, natural wood is directly engineered to serve as functional materials, such as catalytic materials [11,12], supercapacitor [13], lithium-ion battery [14], solar steam generator [15], and 3D bio-scaffold [16], etc., where aligned channels are taken advantage to facilite their performances. However, as far as we know, MA materials with highly aligned pores based on wood have never been addressed.

Here, for the first time we made porous biomass-pyrolized carbon (PBPC) with orderly parallel channel structures by thermal annealing of fir wood, and demonstrate its MA performance parallel to the direction of channel in 2–18 GHz, which is occupied for satellite communications, remote sensing, radar detections, weapons guidance and tracking [17]. In contrast to the intuitive feel that microwave may penetrate the PBPC through the straightway channels, PBPC keeps the ability to attenuate microwave at the same time minimize the reflection at the interface, and shows high

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MA capability. The maximum absorption bandwidth ($RL \leq -10$ dB) [18] reaches 7.63 GHz, and the maximum reflection loss (RL_{max}) reaches −68.3 dB, which is superior to most carbon materials with irregular porous structure. We expect this unique structure will shed light on the design for novel MA materials.

2. Experimental section

2.1. Preparation of PBPCs

The key to PBPC is obtaining the regularly aligned structure, which is accomplished by a two-step process (Fig. 1a): I. Wood was cut into slices and boiled in dilute ammonia to get rid of gums and fatty acids; II. The defatted wood was put into furnace and annealed in nitrogen flow, obtaining PBPCs. Typically, fir wood (fir wood was chosen owning to its regular microstructure) was cut perpendicular to their annual rings into slices, and boiled in 5% dilute ammonia for 6 h to get rid of gums and fatty acids. After that the PBPC precursors were repeatedly washed with deionized water, and freeze-dried to get rid of water. Then, the dried wood precursors were annealed in tube furnace (GSL-1400X, KEJING, HEFEI) at 660, 670, 680, 690, 700 and 720 °C. Heating rate is 2 °C min^{-1}, and it keeps at the highest temperature for 3 h. At last, the sample is cooled to room temperature at cooling rate 5 °C min^{-1}. The samples annealed at different temperatures were denoted as PBPC-660, PBPC-670, and so forth.

2.2. Characterization

Scanning electron microscope (SEM) images were taken on a Hitachi S4800 field-emission SEM system. The TG-FTIR was carried out by a TGA 209 F1 instrument (NETZSCH, Germany) at heating rate of 20 °C min^{-1} in nitrogen atmosphere, coupled with a Thermo Nicolet iS10 FTIR spectroscopy (Thermofisher, Germany). FTIR tests of PBPCs were conducted on a Vector-22 IR spectrometer at room temperature.

X-ray photoelectron spectroscopy (XPS) was operated with ESCALAB 250 photoelectron spectrometer (ThemoFisher Scientific) with Al Kα X-ray source. X-ray diffraction (XRD) was done with BL14B1 beam line station (Shanghai Synchrotron Radiation Facility). Raman spectra were conducted by Renishaw inVia-Reflex Raman Microscopy (excitation wavelength 532 nm) Electrical conductivity was measured with a chi-660e electrochemical workstation by cyclic voltammetry method. The test samples were made cubic and the two sides are adhered to copper foils by silver colloid.

For permittivity tests, the PBPCs were impregnated with wax at 80 °C and then cut into cylindrical specimens with outer diameter of 7 mm and inner diameter of 3 mm; all the samples are 4 mm in thickness. The test was conducted with a ZNB 40 vector network

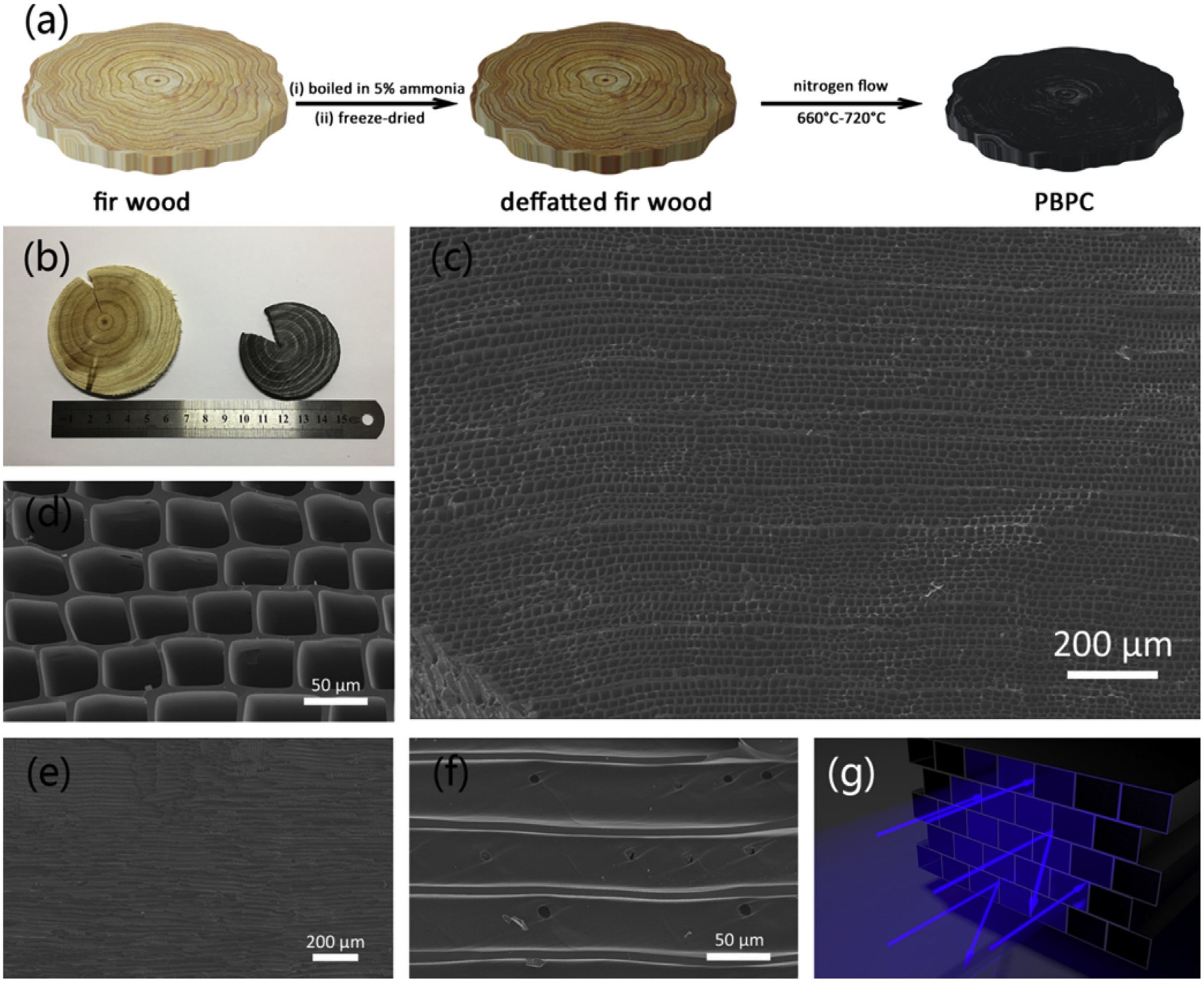

Fig. 1. (a) Fabrication process of PBPC; (b) digital camera photograph of wood and PBPC-680; (c,d) SEM images of radial section of PBPC-680; (e,f) SEM images of the axial section of PBPC-680; (g) schematic representation of microwave absorption mechanism of PBPCs. (A colour version of this figure can be viewed online.)