**Supporting Information**

Elemental doping and size effects modified biomass: a fascinating microwave absorbing/shielding and energy saving material

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**1. Characterization**

**1. 1. BET and BJH parameters**

**Table S1.** The specific surface area and pore parameters of the nanoparticles

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Entry | Sample | Specific surface area (m2/g) | Average pore diameter (nm) | Pore volume (CM3/g) |
| 1 | PAS | 317.7 | 2.42 | 0.0266 |
| 2 | BPAS | 352.6 | 2.42 | 0.0488 |
| 3 | S-BPAS | 624.37 | 2.42 | 0.0574 |
| 4 | P-BPAS | 36.14 | 2.42 | 0.0129 |
| 5 | N-BPAS | 336.08 | 2.42 | 0.0445 |

**1. 2. Elemental analysis**

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N-BPAS

P-BPAS

S-BPAS

BPAS

PAS

**Fig. S1.** EDS spectra of the samples

**Table S2.** Quantitative results of the biomass-derived structures

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elt  PAS | Line | Int | Error | K | Kr | W% | A% | ZAF | Pk/Bg | Class | LConf | HConf |
| **C** | Ka | 311.0 | 4.5530 | 0.7541 | 0.3147 | 55.74 | 62.88 | 0.5645 | 211.15 | A | 54.81 | 56.68 |
| **N** | Ka | 2.9 | 4.5530 | 0.0095 | 0.0040 | 3.45 | 3.33 | 0.1152 | 11.51 | A | 2.85 | 4.05 |
| **O** | Ka | 165.0 | 4.5530 | 0.1993 | 0.0832 | 38.95 | 32.98 | 0.2135 | 86.26 | A | 38.05 | 39.84 |
| **P** | Ka | 30.7 | 4.2147 | 0.0154 | 0.0064 | 0.80 | 0.35 | 0.8070 | 4.76 | A | 0.76 | 0.84 |
| **S** | Ka | 38.2 | 4.2147 | 0.0217 | 0.0090 | 1.07 | 0.45 | 0.8478 | 4.87 | A | 1.02 | 1.12 |
|  |  |  |  | 1.0000 | 0.4173 | 100.00 | 100.00 |  |  |  |  |  |

BPAS

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elt | Line | Int | Error | K | Kr | W% | A% | ZAF | Pk/Bg | Class | LConf | HConf |
| **C** | Ka | 399.9 | 3.1589 | 0.9458 | 0.5991 | 85.18 | 88.89 | 0.7023 | 306.84 | A | 83.79 | 86.57 |
| **N** | Ka | 1.2 | 3.1589 | 0.0038 | 0.0024 | 3.30 | 2.95 | 0.0738 | 16.79 | A | 2.32 | 4.28 |
| **O** | Ka | 17.6 | 3.1589 | 0.0207 | 0.0131 | 9.27 | 7.27 | 0.1412 | 17.29 | A | 8.55 | 10.00 |
| **P** | Ka | 40.7 | 1.9129 | 0.0200 | 0.0127 | 1.53 | 0.62 | 0.8257 | 6.25 | A | 1.46 | 1.61 |
| **S** | Ka | 17.4 | 1.9129 | 0.0096 | 0.0061 | 0.71 | 0.28 | 0.8529 | 3.85 | B | 0.66 | 0.77 |
|  |  |  |  | 1.0000 | 0.6334 | 100.00 | 100.00 |  |  |  |  |  |

S-BPAS

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elt | Line | Int | Error | K | Kr | W% | A% | ZAF | Pk/Bg | Class | LConf | HConf |
| **C** | Ka | 921.4 | 10.2126 | 0.9664 | 0.6854 | 89.79 | 92.41 | 0.7619 | 422.82 | A | 89.02 | 90.55 |
| **N** | Ka | 2.2 | 10.2126 | 0.0031 | 0.0022 | 3.19 | 2.81 | 0.0699 | 30.49 | A | 2.64 | 3.74 |
| **O** | Ka | 19.3 | 10.2126 | 0.0101 | 0.0072 | 5.33 | 4.12 | 0.1342 | 13.08 | A | 5.02 | 5.65 |
| **P** | Ka | 24.1 | 10.8473 | 0.0052 | 0.0037 | 0.45 | 0.18 | 0.8279 | 4.45 | A | 0.43 | 0.47 |
| **S** | Ka | 61.3 | 10.8473 | 0.0151 | 0.0107 | 1.24 | 0.48 | 0.8591 | 5.36 | A | 1.20 | 1.28 |
|  |  |  |  | 1.0000 | 0.7092 | 100.00 | 100.00 |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elt  P-BPAS | Line | Int | Error | K | Kr | W% | A% | ZAF | Pk/Bg | Class | LConf | HConf |
| **C** | Ka | 300.7 | 3.2128 | 0.9443 | 0.5689 | 77.94 | 81.72 | 0.7297 | 210.60 | A | 76.61 | 79.26 |
| **N** | Ka | 4.4 | 3.2128 | 0.0187 | 0.0113 | 13.78 | 12.39 | 0.0817 | 12.96 | A | 11.85 | 15.71 |
| **O** | Ka | 9.2 | 3.2128 | 0.0144 | 0.0087 | 6.64 | 5.23 | 0.1302 | 7.80 | A | 6.00 | 7.29 |
| **P** | Ka | 28.4 | 36.7911 | 0.0185 | 0.0112 | 1.36 | 0.55 | 0.8237 | 5.58 | A | 1.28 | 1.43 |
| **S** | Ka | 5.5 | 36.7911 | 0.0041 | 0.0024 | 0.29 | 0.11 | 0.8530 | 2.75 | B | 0.25 | 0.32 |
|  |  |  |  | 1.0000 | 0.6025 | 100.00 | 100.00 |  |  |  |  |  |

N-BPAS

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Elt | Line | Int | Error | K | Kr | W% | A% | ZAF | Pk/Bg | Class | LConf | HConf |
| **C** | Ka | 656.7 | 4.4498 | 0.9572 | 0.6361 | 88.70 | 91.61 | 0.7152 | 277.38 | A | 87.56 | 89.85 |
| **N** | Ka | 2.5 | 4.4498 | 0.0049 | 0.0033 | 4.62 | 4.09 | 0.0705 | 19.50 | A | 3.65 | 5.59 |
| **O** | Ka | 12.1 | 4.4498 | 0.0088 | 0.0058 | 4.41 | 3.42 | 0.1321 | 6.91 | A | 3.99 | 4.83 |
| **P** | Ka | 20.5 | 9.9838 | 0.0062 | 0.0041 | 0.50 | 0.20 | 0.8296 | 4.16 | A | 0.46 | 0.53 |
| **S** | Ka | 67.3 | 9.9838 | 0.0230 | 0.0153 | 1.77 | 0.69 | 0.8598 | 5.95 | A | 1.70 | 1.85 |
|  |  |  |  | 1.0000 | 0.6646 | 100.00 | 100.00 |  |  |  |  |  |

**1. 3. Microwave absorbing features**

  



**Fig. S2.** Microwave absorption and simulation of matching thickness for the cement-based composites from 8.2 to 18.0 GHz

**Table. S3.** Equations related to the microwave absorbing and shielding features

|  |  |
| --- | --- |
| **Title:** | **Equation/s:** |
| Transmission line theory | , ,, , and |
| Eddy current loss |  |
| Debye relaxation theory |  |
| Quarter wavelength mechanism |  |
| Impedance matching |  |
| Attenuation constant |  |
| Alternative conductivity | ,, and |
| Dissipation factor | , ,and |
| Electromagnetic interference SE | , ,, , and |

**Table. S4.** Definitions of the symbols used to evaluate the microwave absorbing and shielding mechanisms [[1](#_ENREF_1)]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Symbol:** | **Definition:** | **Symbol:** | **Definition:** | **Symbol:** | **Definition:** |
| d | Thickness of absorber | Zin | Input impedance | c | Velocity of light in free space |
| ′ | Real part of permeability | tm | Matching thickness | ″ | Imaginary part of permeability |
| Z0 | Free space impedance | n | Odd number | f | Frequency |
| ′ | Real part of permittivity | fm | Matching frequency | ″ | Imaginary part of permittivity |
| ∞ | Permittivity at the infinite frequency | 0 | Permittivity constant | s | Static permittivity |
|  | Angular frequency |  |  |  |  |

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