Biomass-derived carbon dots embedded in B_2O_3 matrix with high proton density for renewable energy applications

Hern Kim
Department of Energy Science and Technology / Environmental Waste Recycling Institute, Myongji University, Yongin, Gyeonggi-do 17058, South Korea
hernkim@mju.ac.kr

Biomass-derived carbon dots (CDs) are emerging as promising candidates for fluorescent sensing and energy applications due to their tunable optical properties and environmental sustainability. However, their practical utility in renewable energy systems is hindered by low proton density, insufficient Lewis acid sites, poor ionic conductivity, and a strong tendency to aggregate. Herein, CDs from coffee waste are systematically embedded in a boron oxide (B_2O_3) matrix using boric acid (BA) as boron source via hydrothermal method. The resulting composite (BA1CD) serves as a metal-free catalyst for hydrogen generation through sodium borohydride (NaBH4) methanolysis. The B_2O_3 matrix induces Lewis acid sites in BA1CD that activate methanol for the reaction. Consequently, BA1CD exhibits remarkable catalytic activity for hydrogen generation, with a high hydrogen generation rate (139 L H^2 g^{-1} min^{-1}) and low activation energy (26.2 kJ/mol). Furthermore, BA1CD is incorporated as functional filler into polyacrylamide (PAM) hydrogel for triboelectric nanogenerator (TENG). Interestingly, B_2O_3 matrix promotes uniform dispersion of the CDs and prevents the aggregation of CD in the PAM hydrogel. Therefore, BA1CD/PAM hydrogel demonstrates superior TENG performance with high output voltage (37.8 V) and current density (6.6 mA/m^2), successfully powering various low-voltage everyday devices. This study provides a sustainable and multifunctional approach for biomass valorization toward advanced energy harvesting and storage technologies.