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Biosynthesized Nitrogen-Zinc-Codoped Copper Oxide Nanoparticles for Photocatalytic Activity: Bandgap Engineering of Nanomaterials

Abstract:

In the era of science and technology, nanoscience has explored the potential of nanoparticles (NPs) due to their extraordinary properties at nanoscale compared to those of bulk materials. Modifying metal oxide semiconductors through innovative and sustainable approaches is crucial to meet specific requirements for targeted applications. Herein, semiconductor modified N-Zn-codoped CuO NPs was successfully synthesized as highly efficient photocatalyst using Pycnostachys Abyssinica Fresen plant leaf extract as a bioreducing and capping agent for the degradation of methylene blue (MB) under natural sunlight irradiation. Additionally, pure CuO NPs, N-CuO NPs, and Zn-CuO NPs were also biosynthesized for comparison. Characterization via UV–Vis, XRD, SEM, and FT-IR revealed that N-Zn codoping narrowed the band gap (1.72 to1.07 eV), reduced the crystallite size (25 to11.23 nm), distorted the monoclinic crystal lattice (rhombus- and diamond-like shapes with an average diameter of 2.25 µm to an irregular shape with an average size of 2.75 µm), and redshifted the Cu–O characteristic peaks (617 to 529 cm-1) of CuO NPs, confirming the successful incorporation of dopants into CuO NPs. The effects of key parameters on the photocatalytic degradation efficiency of all biosynthesized NPs were investigated. The optimal conditions for maximum degradation of N-Zn-CuO NPs were a 3% dopant concentration for both N and Zn, a 120 mg photocatalyst dosage, a pH of 11, a 20 ppm initial dye concentration and a 30-minute reaction time. The photocatalytic activity toward MB dye degradation after 30 minutes of exposure to sunlight was 99.75% for the N-Zn-CuO NPs, outperforming that of the pure CuO NPs (95.76%), N-CuO NPs (97.93%), and Zn-CuO NPs (98.26%) under optimal conditions. The enhanced photocatalytic performance of N-Zn-CuO NPs is attributed to their tailored optical properties, leading to improved charge separation and reduced recombination. Kinetic studies revealed a strong fit (R2=0.99799) with the BMG kinetic model for N-Zn-CuO NPs, indicating surface-mediated degradation of MB. Furthermore, the nanocatalysts exhibited excellent reusability and stabil-

ity over four cycles. These findings highlight the potential of biosynthesized N-Zn-CuO NPs as highly efficient, simple, eco-friendly and sustainable solutions for the degradation of organic pollutants.

Biography

Yohannes Shuka is a 29-year-old Ethiopian chemist who graduated with honors with a Master of Science in Physical Chemistry from Hawassa University in 2024. He is currently a PhD candidate at UniME in Italy. Since 2020, he has served as the Chief Lab Chemist and lecturer in Physical Chemistry, conducting research on the theme of "Nanotechnology Applications for Green Development" at Madda Walabu University and Borana University in Ethiopia, respectively. He has received various awards from national and international institutions in recognition of his outstanding academic and research achievements. Yohannes has published seven papers in reputable journals and serves as a member of the editorial board and as a peer reviewer for four journals.