Supplementary Materials

Insight into the Structural and Performance Correlation of Photocatalytic TiO_2/Cu Composite Films Prepared by Magnetron Sputtering Method

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Normalizing the XRD results ensures comparability between different samples (Fig. S1). This process involves adjusting the XRD signal intensity of each sample to match a reference peak (usually from the substrate or another known material), thereby eliminating variations caused by factors such as sample thickness, density, equipment settings, or uneven sample loading. Doing so allows for a more accurate comparison of the relative intensity and position of crystalline phases across samples, facilitating a clearer analysis of the effects of doping elements or other experimental variables on the crystal structure of the samples.

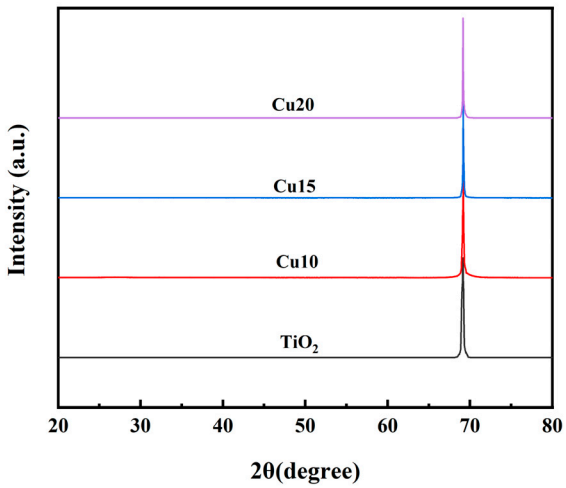


Fig. S1 The XRD normalization results.

To further clarify the distribution of Cu, an energy dispersive spectroscopy (EDS) mapping was performed on the cross-section of the samples, with the relevant results shown in Figure S2.

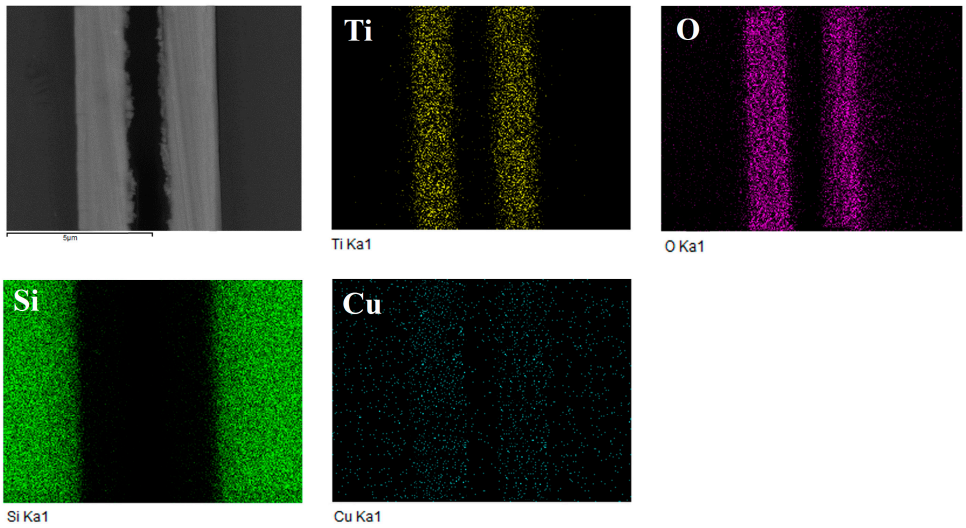


Fig. S2 The EDS surface scan analysis of the Cu15 cross-section.

An EDS elemental analysis was conducted on the particles aggregated on the surface of the Cu20 film, with the results shown in Figure S3.

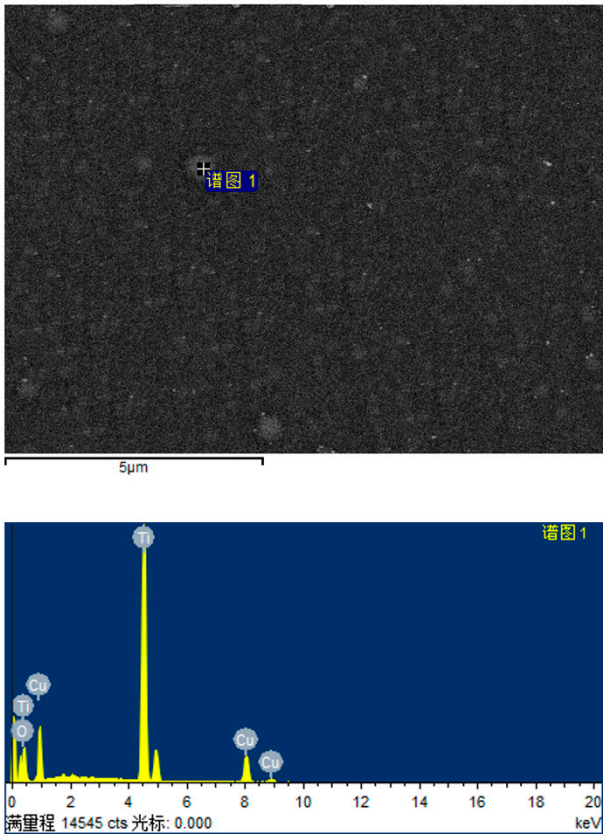


Fig. S3 EDS elemental analysis on the surface-clustered particles of Cu20 film.

The comparison between the antibacterial results under natural light and dark conditions reveals that Cu-doped TiO_2 films exhibit smaller inhibition zones under light conditions compared to dark conditions. Furthermore, under light conditions, films with lower Cu doping (Cu10) show better

antibacterial performance than those with higher Cu doping levels (Cu20). This can be attributed to several key factors.

Firstly, under dark conditions, the antibacterial properties of Cu are more pronounced. Copper ions (Cu^{2+}) can disrupt bacterial cell walls or induce oxidative stress within cells, effectively inhibiting bacterial growth. This antibacterial mechanism is independent of light, so even in the absence of light, Cu can exhibit strong antibacterial effects. Additionally, under dark conditions, without light-induced redox reactions, the antibacterial activity of Cu is not compromised by light, allowing it to be fully expressed.

However, when the Cu doping level is higher, excessive reactive oxygen species generated during the photocatalytic process may react with Cu, leading to the formation of oxides on the Cu surface (such as CuO or Cu_2O), thereby reducing the release of Cu^{2+} ions. This, in turn, diminishes the antibacterial activity of Cu.

Furthermore, UV–visible spectroscopy analysis shows that as the Cu content increases, the bandgap of the TiO_2/Cu films initially decreases at Cu10 but then increases. This change is closely related to the behavior of Cu doping and its oxidation state under light conditions.

Cu doping can introduce additional electronic states, facilitating the generation of photogenerated electron–hole pairs and enhancing photocatalytic activity. However, when the Cu content continues to increase beyond a certain threshold, the bandgap instead increases. Combining this with the previous discussion, under light conditions, the oxidation induced by high Cu content not only weakens the antibacterial activity of Cu but also alters the bandgap of the material, affecting the photocatalytic effect of TiO_2. With the increased bandgap, photocatalytic efficiency decreases, resulting in insufficient generation of reactive oxygen species, which further weakens the antibacterial performance. This explains why under light conditions, the antibacterial performance of films with higher Cu content is inferior to those with lower Cu content.

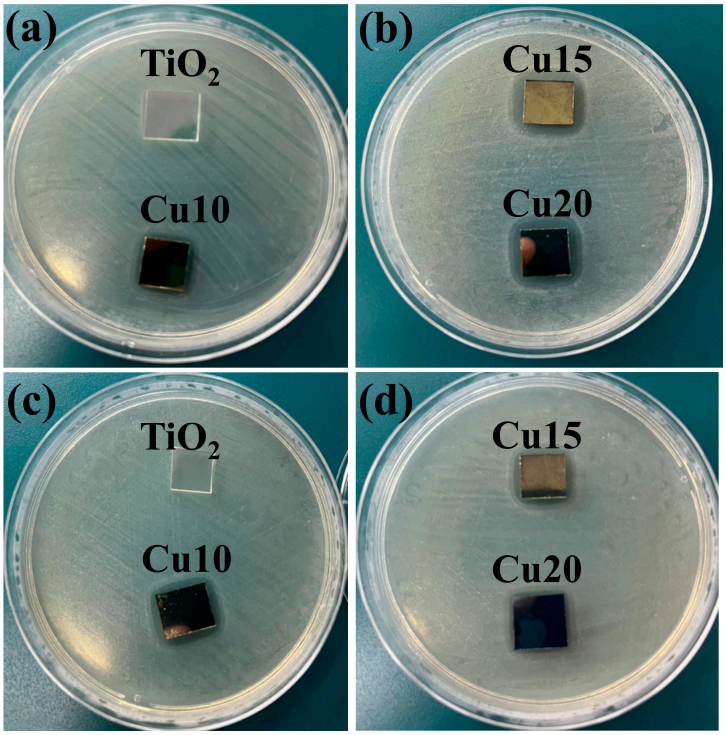


Figure 7 Antibacterial effect of TiO_2/Cu composite film under illumination (a, b) Escherichia coli, (c, d) Staphylococcus aureus.