Scalable and Gas-Free Plasma Systems for Extreme Biofilm Eradication

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Bacterial biofilms are complex structure inherently formed by microbial communities, primary made of extracellular polymeric substances. The formation of biofilm is a multi-step process, generally involving attachment, aggregation, maturation, and dispersal. This process can be influenced by environmental factors and always in progression either slowly or more rapidly. Biofilms are a significant contributor to healthcare associated infection (HAI) when they are formed on various surfaces including medical devices, pipes and sinks, and even obstructed dry surfaces, serving as a reservoir for pathogens and increasing the risk of HAI. Biofilm-associated bacterias thus exhibit markedly increased antibiotic resistance that may be attributed to factors such as restricted drug penetration and adaptive stress responses. *Acinetobacter baumannii* a clinical isolate from patient wound and *Staphylococcus aureus* a laboratory reference strain are obtained from Universiti Malaya Medical Centre. *A. baumannii* is known for being a significant cause of HAI and *S. aureus* is also a common cause of infections, both in hospitals and in the community. These two strains of antimicrobial resistance are also identified as high biofilm producers.

In this study, we introduce two atmospheric pressure plasma systems; a gas-free capillary-guided corona discharge (CGCD) and a surface dielectric barrier discharge (SDBD) systems designed to achieve rapid, ultrahigh biofilm eradication. The two configurations shown complete removal of viable microorganisms in the biofilm samples measured through the CFU (colony-forming unit) method. The CGCD achieved a 8-log reduction (99.999999% elimination) at the optimum conditions within minutes of treatment. This exceptional performance arises from synergistic plasma-generated reactive oxygen/nitrogen species, UV photons, and localised high electric fields, which collectively degrade biofilm matrices and induce irreversible cellular damage. The morphology of *A. baumannii* observed under field-emission scanning electron microscopy is shown in Figure 1.

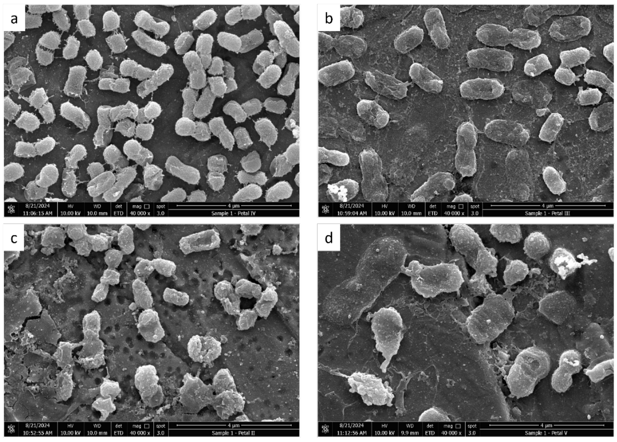

Figure 1 Field-emission scanning electron microscopy of *Acinetobacter baumannii* at 40,000x magnification of (a) untreated and plasma treated samples: (b) 1 minute, (c) 3 minutes, and (d) 5 minutes, indicating the disintegration of cell structure after 1 minute.

The SDBD system demonstrated comparable efficacy across larger treatment areas. Critical to optimizing these systems, we correlate discharge formation with electrical characterization to electrode geometry. High-speed intensified CCD imaging captures discharge dynamics and propagation of plasma plume in the afterglow region. By bridging scalable engineering (SDBD) with precision-targeted therapy (CGCD), this work establishes a framework for tailoring plasma systems to specific applications for bacterial biofilm removal. The integration of multiple diagnostics helped to validate synergetic effect of plasma treatment and provides actionable insights for optimizing system parameters, offering a pathway to combat antimicrobial resistance through the physics-driven solution.

Keywords: Atmospheric pressure plasma, biofilm eradication, gas-free plasma, reactive species, surface dielectric barrier discharge