Water treatment using low temperature plasma dielectric barrier discharge at atmospheric pressure

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Low temperature plasma or non-thermal plasma is a novel technology for water treatment with increasing amount of research articles published every year focusing on this topic. The reactive species generated during plasma water treatment under atmospheric pressure can be divided into two categories: reactive oxygen species (ROS: OH, O*, H_2O_2, O_3 etc) and reactive nitrogen species (RNS: NO, NO_2, NO_3, HONO, HNO_2, NH etc). Plasma based water treatment could be potentially modularized and scaled-up for in-situ water resource utilization during future crewed space missions or point of use applications in regions lacking water treatment infrastructure as well as integrated with conventional water treatment systems [1].

A flexible printed circuit board (PCB) plasma source and a packed-bed reactor both employ low temperature plasma dielectric barrier discharge (DBD) are designed and manufactured. The design schematic diagram of a surface DBD plasma source for water treatment is shown in Figure 1. As can be seen, the designed plasma source consists of five layers: two layers of copper electrodes printed on both sides of a base dielectric layer, and two polyimide cover layers on top of each electrode layer respectively. There is an orifice in the middle of each hexagon pattern to allow air passing through for rapid injection of reactive species into water via bubbling.

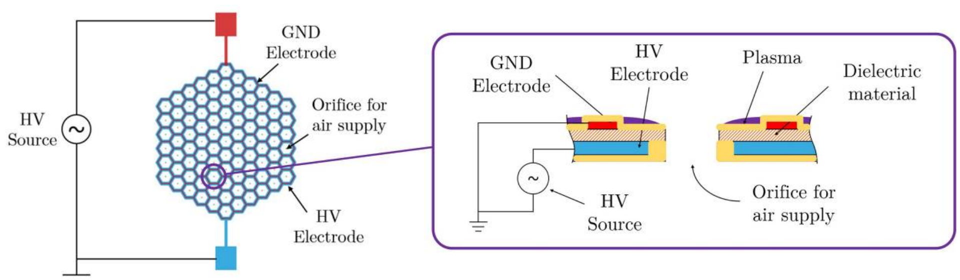

Figure 1 Surface DBD plasma source

The electrical characteristics of the plasma source operating at 5 kHz is displayed in Figure 2a and b. As can be seen, the applied voltage peak-to-peak value, V_{pp} is 6.0 kV, the breakdown voltage evaluated from the active phase is around 1.25 kV. Based on the Lissajous figure shown in Figure 2b, the energy per period of the plasma source is 288.3 mJ, leading to a consumption power of 1.44 W in this operating condition. Figure 2c demonstrates the conceptual design [2] of the plasma reactor for water treatment, air is injected from the bottom of the reactor, a hydrophobic membrane is used to separate the liquid and the plasma source. During operation, the injected air will carry the plasma activated radical species and generates bubbling inside the liquid to enhance the mass transfer between gas and liquid phase. A 3D printed grail reactor with cup threads for quick instalment is displayed in Figure 2d, details of this reactor will be published later in a journal article.

Figure 2 Electrical characteristics of the surface DBD and reactor design (**a**) Voltage and current waveform (**b**) Lissajous figure based on the charge measured using a monitor capacitor (**c**) Conceptual reactor design (**d**) Grail plasma reactor

Two different membranes, a porous hydrophobic PTFE membrane and a PTFE sheet with 1 mm hole, are tested with organic dye methylene blue (MB) solution at the concentration of 10 mg/L. The treatment volume is 100 mL and the chosen air flow rate is 2.0 standard litre per minute (SLPM). Absorption spectroscopy is employed to quantify the amount of remaining MB in the plasma treated water and estimate the MB degradation efficiency. The absorbance data measured using a spectrometer and their corresponding MB samples are demonstrated in Figure 3a and b respectively. Based on the MB degradation efficiency at various plasma treatment time shown in Figure 3c, the MB is completely decontaminated after 25 min plasma treatment time for porous hydrophobic PTFE membrane case, and after around 16 min for PTFE sheet with 1 mm hole case. Yield, $Y=V\cdot\Delta C(t)/(P\cdot t)$ in g/kWh, is one of the figure-of-merit used for comparing different plasma reactors for water treatment in the plasma water treatment community. V is the treatment volume, C is the contaminants concentrations, P stands for the power consumption of the reactor, and t is the plasma treatment time. The MB degradation yield as a function of efficiency is shown in Figure 3d. Malik [3] proposed