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Nanosecond Plasmas in Liquids – Dynamic Plasmas at GPa pressures

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Abstract - Plasmas inside and in contact with liquids have been a highly promising field of study for the decontamination of water, wound healing in the field of plasma medicine and modification of metallic and organic surfaces which are in contact with the treated liquid. Especially the ignition of a plasma inside a liquid has generated special interest due to the enhanced mass transfer of the reactive species inside the liquid. Those plasmas can be ignited by different techniques such as the insertion of gas bubbles where the plasma discharge appears inside these bubbles or the discharge directly at a high voltage electrode which is immersed inside the liquid. The understanding of the physics of the plasma ignition and sustainment is, however, still in its infancy due to the complexity of the phenomenon. Plasma generation depends on the characteristics of the plasma electrode, the powering of the electrode, and the properties of the liquid. For example, if the rise time of the voltage is of the order of many microseconds, the Ohmic heating of the liquid by the dc current will locally cause water vapour bubbles to be formed until the ignition criterion inside that bubble is met. A plasma is generated in the void and the plasma pressure continues to increase the bubble. If, however, the rise time of the voltage is of the order of ns and the voltage several kV, electrostriction is very large so that rupture of the liquid occurs at a negative pressure of at least 24 MPa. Cavitation voids are formed and ignition inside these voids may occur. Ignition converts the liquid spontaneously in the plasma state, which then expands this initial void to form a bubble. This creates a pressure pulse of the order of 10s of GPa depending on the HV voltage and the emission of acoustic waves that can be observed via shadowgraphy. At the same time, the plasma pressure expands the initial bubble until a specific size is reached before the counteracting force due to surface tension causes this bubble to collapse. This sequence is monitored by shadowgraphy and compared to cavitation theory. The dissipated energy by the plasma drives the adiabatic expansion of water vapor inside the bubble from its initial super critical state to a low pressure, low temperature state at maximum bubble expansion reaching values of 10^3 Pa and 50 K, respectively. These predictions from cavitation theory are corroborated by optical emission spectroscopy (OES).

Short Bio

Achim von Keudell is professor of experimental physics at Ruhr-University Bochum. His research focuses on surface processes in reactive plasmas by employing optical in-situ real time diagnostics and quantitative mass spectrometry. His team developed unique particle beam experiments to study heterogeneous surface reactions being relevant to the plasma boundary. His group works now on reactive microplasmas, on reactive high power impulse magnetron sputtering, and on plasma in liquids. He is currently the speaker of SFB 1316 “Transient Atmospheric Pressure Plasmas – from plasma to liquids to solids”.