Ultrafast X-ray provides new look at plasma discharge breakdown in water

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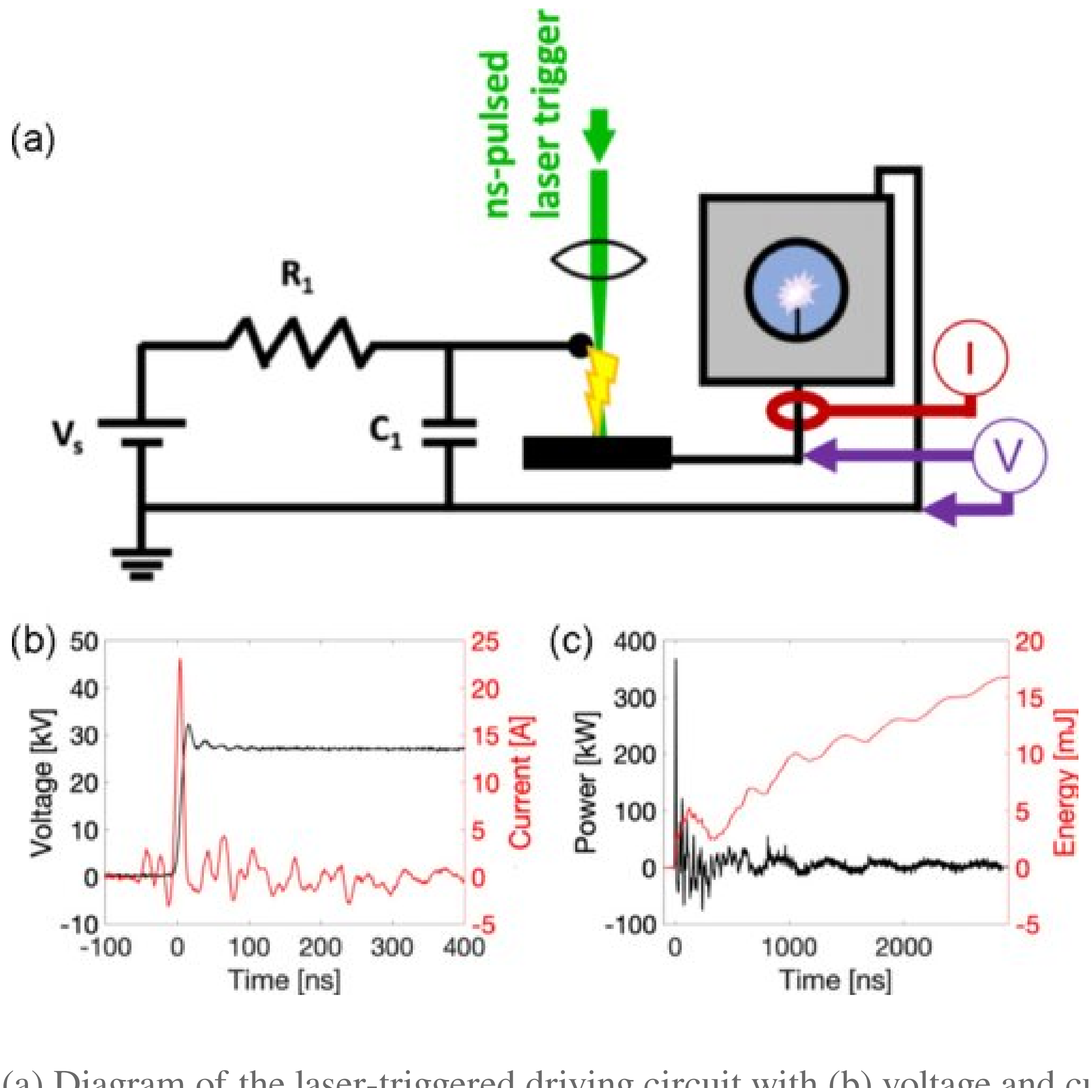

(a) Diagram of the laser-triggered driving circuit with (b) voltage and current traces for a typical event. (c) Power and energy calculated from direct integration. Credit: Texas A&M University

Occurring faster than the speed of sound, the mystery behind the breakdown of plasma discharges in water is one step closer to being understood as researchers pursue applying new diagnostic processes using state-of-the-art X-ray imaging to the challenging subject.

These diagnostic processes open the door to a better understanding of plasma physics, which could lead to advances in green energy production through methods including fusion, hydrocarbon reforming and hydrogen generation.

Dr. David Staack and Christopher Campbell in the J. Mike Walker '66 Department of Mechanical Engineering at Texas A&M University are part of the team pioneering this approach to assessing plasma processes. Partners on the project include diagnostics experts from Los Alamos National Laboratories and using the facilities at the Argonne National Laboratory Advanced Photon Source (APS).

The team is working with LTEOIL on patented research into the use of multiphase plasma in carbon-free fuel reforming. The research is supported by the dynamic materials properties campaign (C2) and the advanced diagnostics campaign (C3) at Los Alamos National Laboratories through the Thermonuclear Plasma Physics group (P4) principal investigator, Zhehui (Jeph) Wang.

The research, which was recently published in *Physical Review Research*, is producing the first-known ultrafast X-ray images of pulsed plasma initiation processes in water. Staack, associate professor and Sallie and Don Davis '61 Career Development Professor, said these new images provide valuable insight into how plasma behaves in liquid.

"Our lab is working with industry sponsors on patented research into the use of multiphase plasma in carbon-free fuel reforming," Staack said. "By understanding this plasma physics, we are able to efficiently convert tar and recycled plastics into hydrogen and fuels for automobiles without any greenhouse gas emissions. In the future, these investigations may lead to improvements in inertial confinement fusion energy sources."

Inertial confinement fusion—in which high temperature, high energy density plasmas are generated—is a specific focus of the project. To better understand the plasma physics involved in this type of fusion, Staack said the team is developing short timescale, high-speed imaging and diagnostic techniques utilizing a simple, low-cost plasma discharge system.

Additionally, they are seeking to better understand the phenomena that occur when plasma is discharged in liquid, causing a rapid release of energy resulting in low-density microfractures in the water that move at over 20 times the speed of sound.

Campbell, a graduate research assistant and Ph.D. candidate, said the team hopes their discoveries can prove to be a valuable contribution to the collective knowledge of their field as researchers seek to develop robust predictive models for how plasma will react in liquid.

"Our goal is to experimentally probe the regions and timescales of interest surrounding this plasma using ultrafast X-ray and visible imaging techniques, thereby contributing new data to the ongoing literature discussion in this area," said Campbell. "With a complete conceptual model, we could more efficiently learn how to apply these plasmas in new ways and also improve existing applications."

Although they have made progress, Campbell said current methods are not yet sophisticated enough to collect multiple images of a single plasma event in such a short amount of time—less than 100 nanoseconds.

"Even with the state-of-the-art techniques and fast framerates available at the Advanced Photon Source, we have only been able to image a single frame during the entire event of interest—by the next video frame, most of the fastest plasma processes have concluded," Campbell said. "This work highlights several resourceful techniques we have developed to make the most of what few images we are able to take of these fastest processes."

The team is currently working to measure the pressures induced by the rapid phenomena and preparing for a second round of measurements at APS to investigate interacting discharges, discharges in different fluids and processes that may limit confinement of higher energy discharges. They look forward to the opportunity of using even higher-framerate X-ray imaging methods ranging up to 6.7 million frames per second, compared to 271 thousand frames per second in this study.

More information: Christopher Campbell et al, Ultrafast x-ray imaging of pulsed plasmas in water, *Physical Review Research* (2021). DOI: 10.1103/PhysRevResearch.3.L022021

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