VISCOUS DROPLET IN A NONTHERMAL PLASMA: MICROFLOW AT PLASMA-LIQUID INTERFACE

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The interaction of a dielectric barrier discharge plasma and a silicone-oil liquid droplet in a Hele-Shaw cell was investigated experimentally employing the synchronized optical and electrical temporally resolved measurements [1]. In the pioneering work of Chu and Hou et al. [2, 3] it was shown that local change of properties at the oil-plasma interface caused by actions of plasma can induce a radial viscous fingering. Now we follow and extend the research with exploring the crucial influence of a higher applied voltage and analysing detailed temporal development over the complete lifespan of the investigated events. The perturbation wavelength and the temporal development of fingering speed, plasma-liquid interface length, mean transferred charge and fractal dimension of the pattern were determined. Large set of synchronized optical recordings enabled not only a unique quantified picture of the whole phenomenon but also a very useful experimental data available for a direct comparison with possible future computer simulations. The recorded changes in the dissipated mean power showed a strong correlation to the subsequent stretching of the interface, also opening new methodological possibilities for the future investigations. The parametric study showed that oil viscosity and applied voltage amplitude both had significant impact on the interface evolution. Notably, at relatively high voltages the destabilized interface featured properties noticeably diverging from the theoretical prediction of a known model. We proposed an explanation based on the change of the liquid viscosity with increased heating at high applied voltage amplitudes. Furthermore, we were able to quantify spatially resolved dissipated power density, i.e. the main cause of the whole process, and the unstable plasma-liquid interface local velocity, i.e. the main result of the process. It will be demonstrated in the next paper, how the irregular distribution of these parameters can lead to the observed microflow.

[1] L. Potocnakova, P. Synek, and T. Hoder 2020 Phys. Rev. E 101, 063201
[2] H.-Y. Chu and H.-K. Lee 2011 Phys. Rev. Lett. 107, 225001
[3] S.-Y. Hou and H.-Y. Chu 2015 Phys. Rev. E 92, 013101
[4] T. Hoder, P. Synek and J. Vorac 2019 Plasma Sources Sci. Technol. 28, 105016

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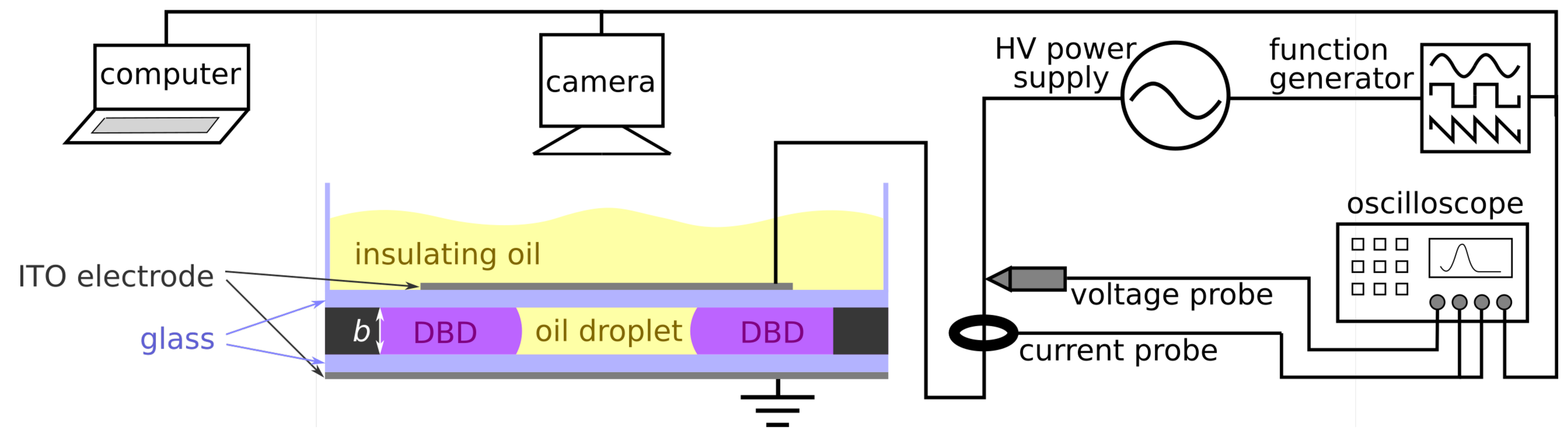
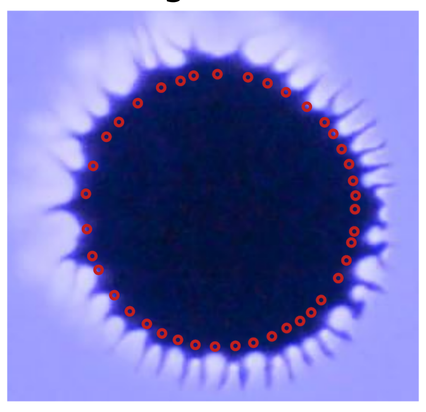
EXPERIMENT

- DBD discharge setup as a Hele-Shaw cell with typical gap width 0.1 mm
- 12.5 kHz voltage with max. amplitude 10 kV
- 1-10 µl droplets of polydimethylsiloxane oil with viscosities 50-500 mm²/s
- high resolution fast voltage and current probes
- synchronized greyscale ICCD imaging and non-synchronized color imaging with digital camera

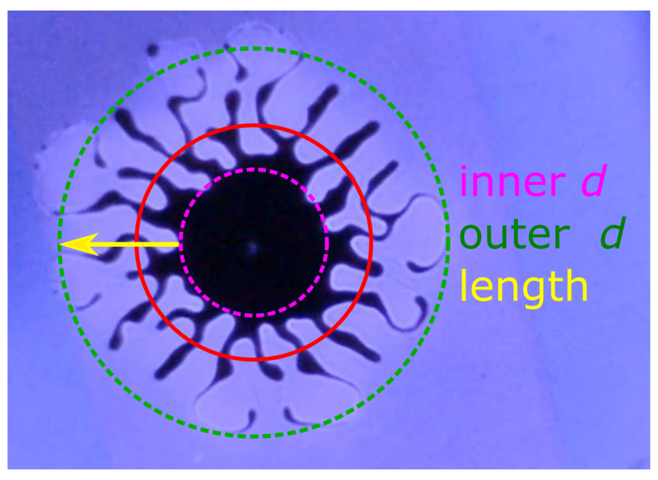


METHODS

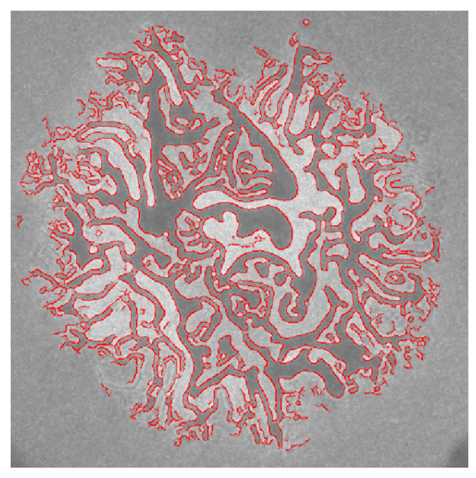
Wavelength determination



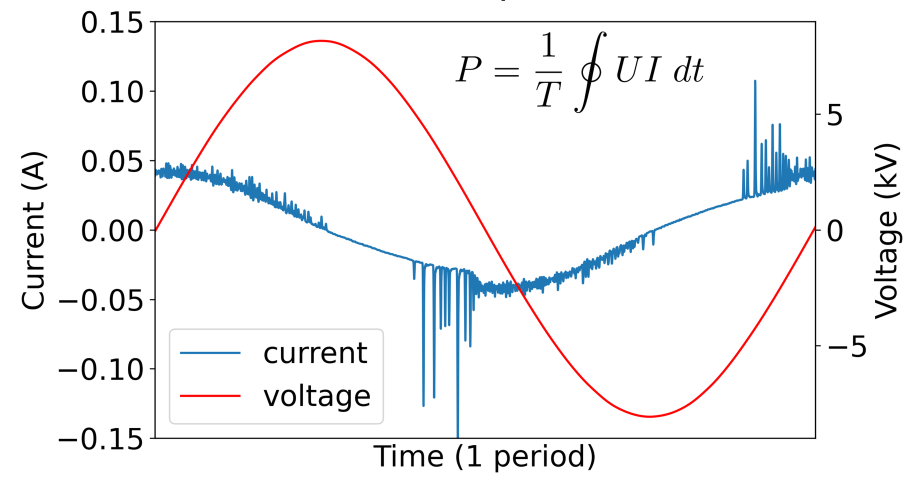
Evaluating visual parameters



Interface length tracking

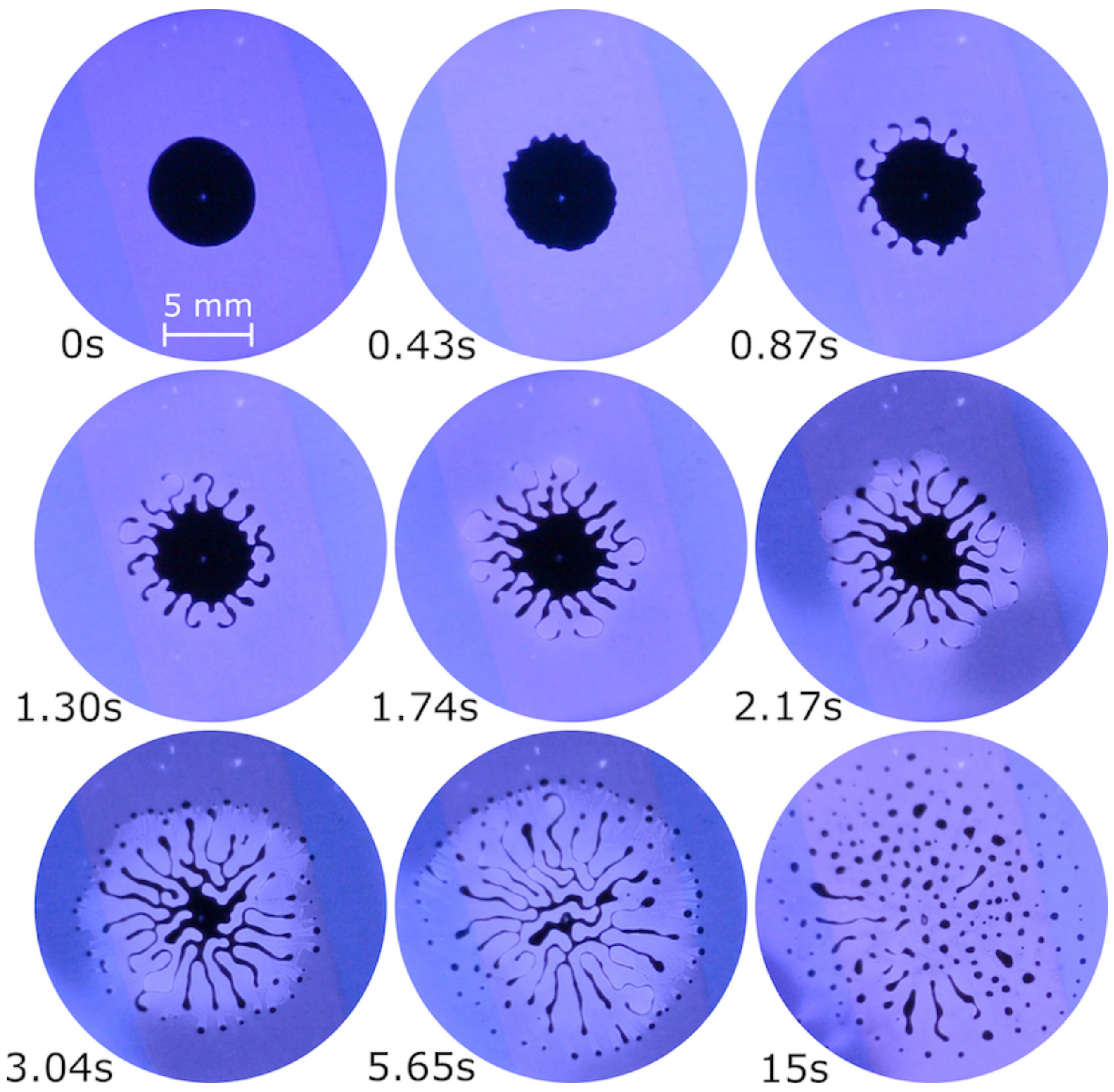


El. characteristics [4] and power determination

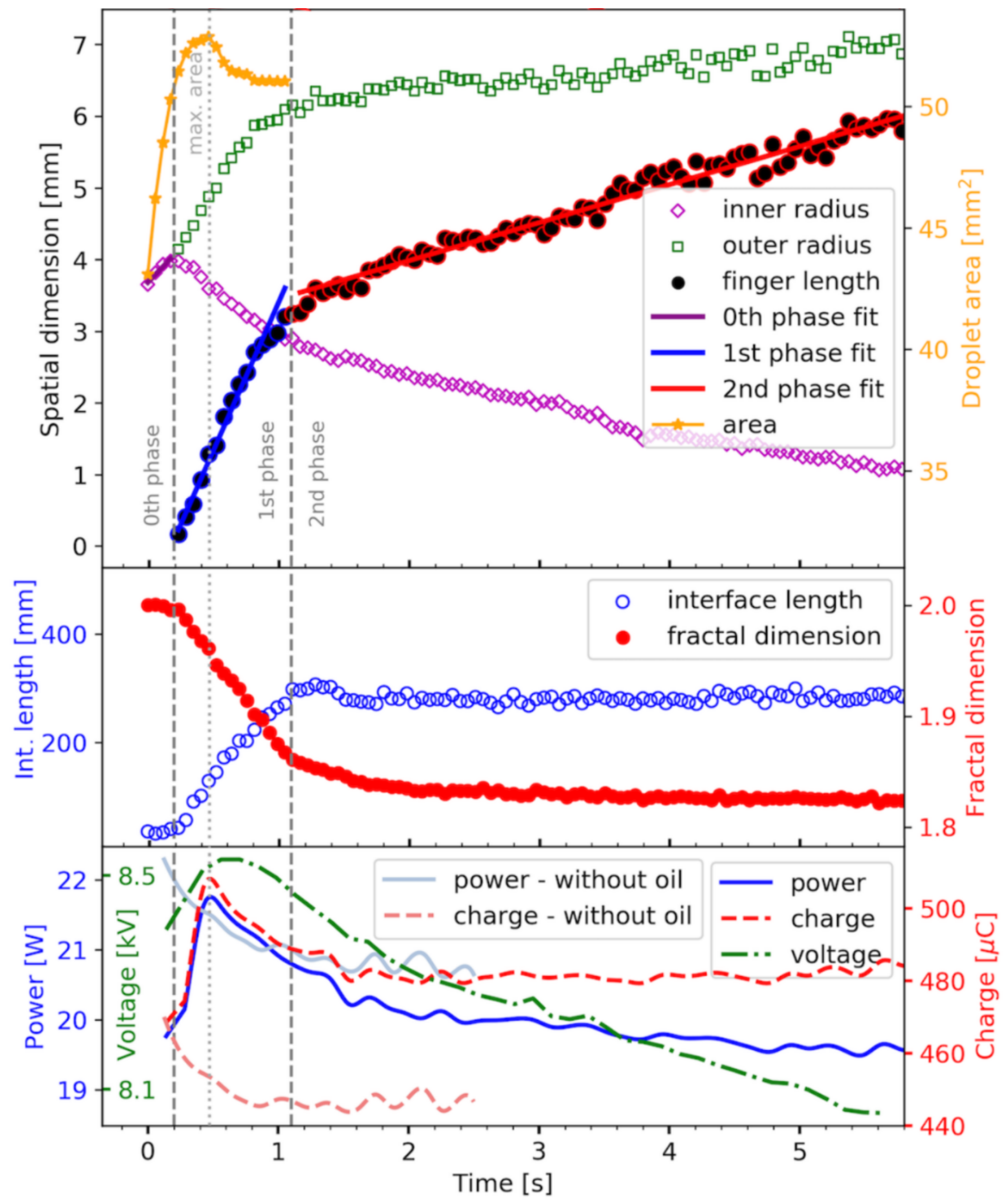


RESULTS

Temporal overview of the whole process:
- 0th phase: electrostatic attraction, droplet's area increases
- 1st phase: initial instability with typical wavelength, followed by abrupt and fast oil expansion
- 2nd phase: gradual streching and folding of oil channels, often finished with fragmentation into secondary droplets

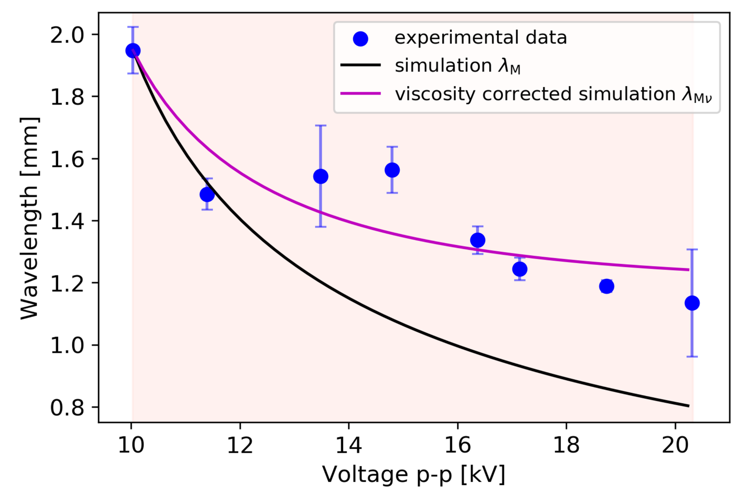


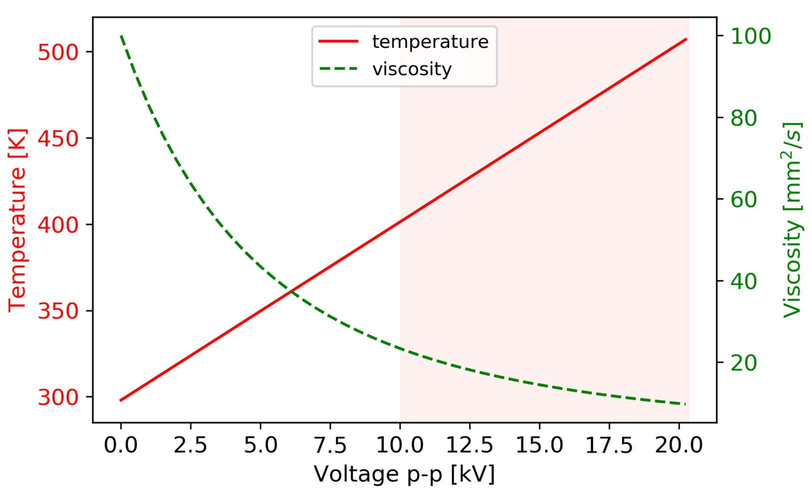
Time resolved evolution of multiple global process-defining parameters



Theoretical model corrected by temperature-dependency of viscosity

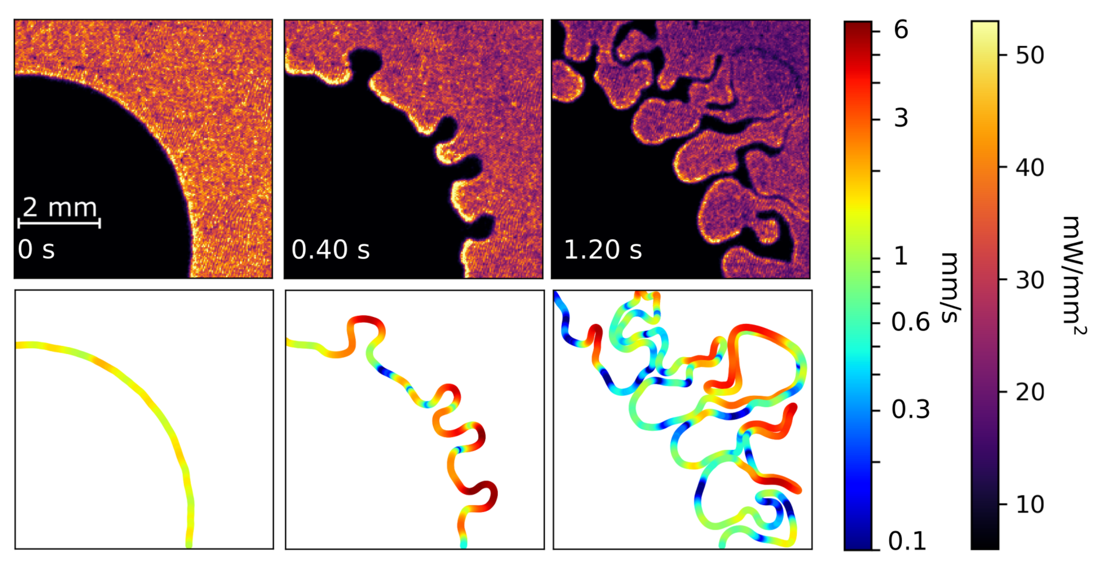
$$\lambda_M = \lambda_{\min}\left(\frac{1-\frac{v_{\min}\nu_0\rho_0}{\sigma_0}C\Delta U_{pp}}{1+C\Delta U_{pp}}\right)^{1/2} \qquad A(T)=\sqrt{\frac{\nu(T)_{U_{pp\,\min}}}{\nu(T)_{U_{pp}}}} \qquad \lambda_{M\nu} = \lambda_M A(T)$$



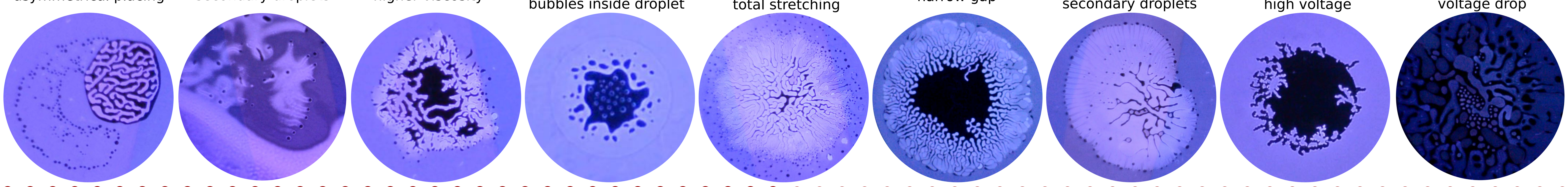


WORK IN PROGRESS

Time resolved 2D maps of power density and spatially resolved interface speed



asymmetrical placing · secondary droplets · higher viscosity · low voltage, bubbles inside droplet · high voltage, total stretching · narrow gap · full ring of secondary droplets · high viscosity, high voltage · oil re-grouping after voltage drop



"You don't deserve me at my best, if you can't handle me at my worst..."