Explosive Boiling Of Thin Cu Wires: Experiments And Simulations

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Abstract

The simplicity, reliability and low costs of electro-mechanical breakers have made them the workhorse for the interruption of low voltage short-circuit currents. In the presence of a short circuit, the contacts of the breaker heat up, and a bridge of molten metal forms between the pair of contacts. The separation of the contacts by electromagnetic forces, combined with Joule heating and magnetic pinch forces, lead to the explosion of the molten bridge and to the ignition of an electric arc [1], which the circuit breaker must extinguish [2]. As shown in Ref. [3], single wire explosion tests on thin Cu wires can be used to shed light on the processes underlying the arc ignition in short-circuit breakers.

Here, we report experiments and simulations on the explosion of Cu wires in the presence of currents that increase nearly linearly with rates di/dt between 1 and 10 kA/ms. The test object consists of a Cu wire with a diameter of 0.127 or 0.3 mm mounted between two Cu electrodes. Figure 1(a) shows the time-dependence of the current and the voltage of the test object. From the time-dependence of the voltage near t = 0, we deduce that the inductance of the test object is 10 µH, in good agreement with the results of 3-dimensional COMSOL Multiphysics® simulations performed with the AC/DC Module and the CAD Import Module.

With increase time and current, the wire temperature increases, leading to the test object voltage increase seen in Fig. 1. The voltage peak near 2.2 kV at 0.21 ms is associated with the explosion of the wire. Using the Heat Transfer Module and the AC/DC Module of the COMSOL Multiphysics® software, we simulate the time-dependence of the test object voltage. Our 2-dimensional simulations include Joule heating of the wire, convective and radiative cooling, as well as temperature dependent material properties (inset of Fig. 1). We assume also that the explosion occurs once the section of the wire has reached boiling temperature. In both the experiments and the simulations, the explosion time varies like $(di/dt)^{-2/3}$, thus confirming that the wire explosion occurs by explosive boiling and not by the magnetic pinch effect.

Reference

[1] P. G. Slade, IEEE Transactions on Plasma Science, IEICE Trans. Electron., E93-C 1380-1386 (2010).
[2] P. Corfdir, T. Delachaux, P. Sütterlin, M. Abplanalp, F. Kassubek, and M. Bator, J. Phys. D.: Appl. Phys., 53 385206 (2020).
[3] P. Corfdir, T. Delachaux, P. Sütterlin, M. Abplanalp, and M. Bator, accepted for publication (2023).

Figures used in the abstract
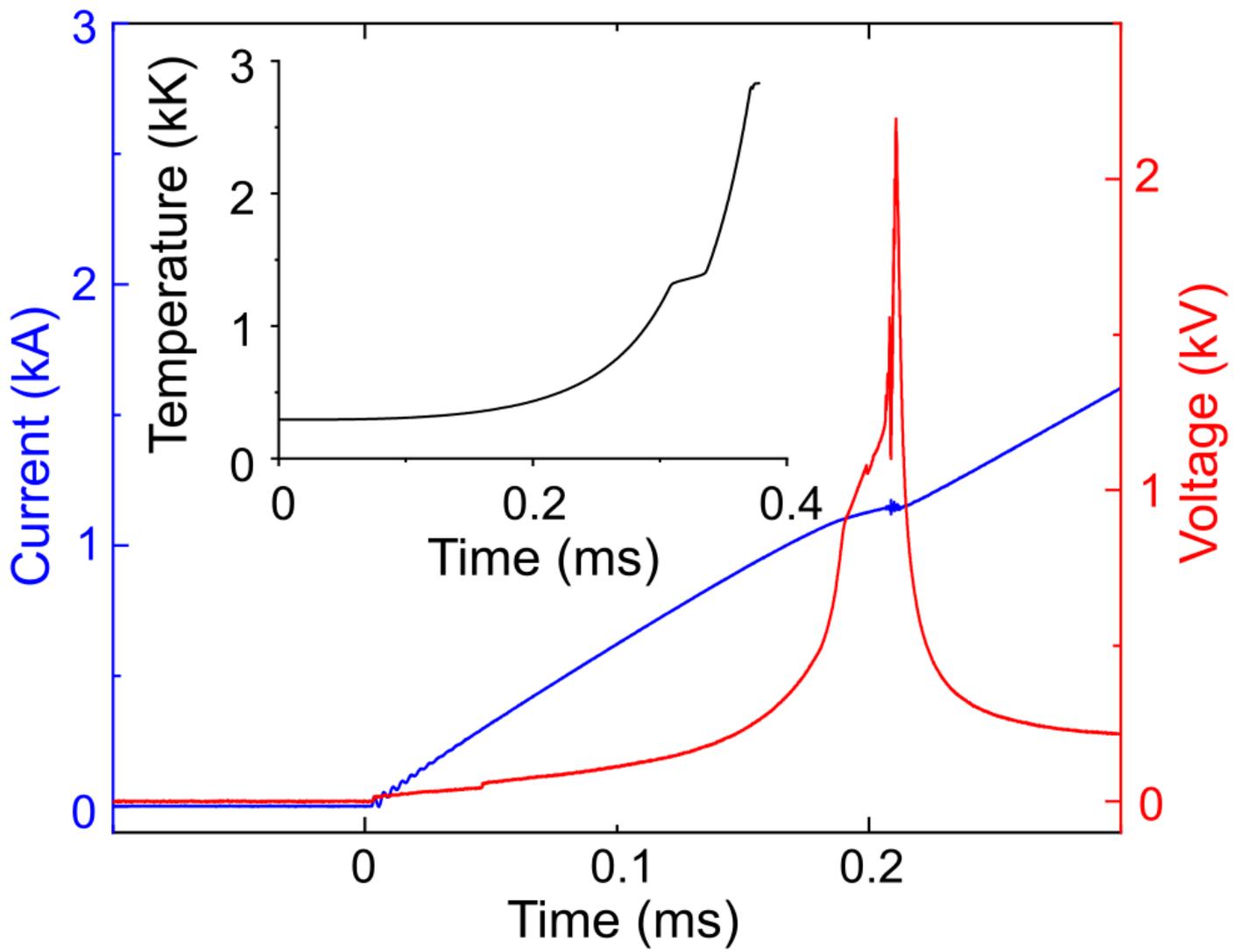
Figure 1 : Figure 1: Current (blue) and voltage (red) measured during the explosion of a 0.127 mm diameter Cu wire with di/dt = 5.3 kA/ms (inset) Simulated temperature of a 0.127 mm Cu wire in the presence of a current with di/dt =6.5 kA/ms.