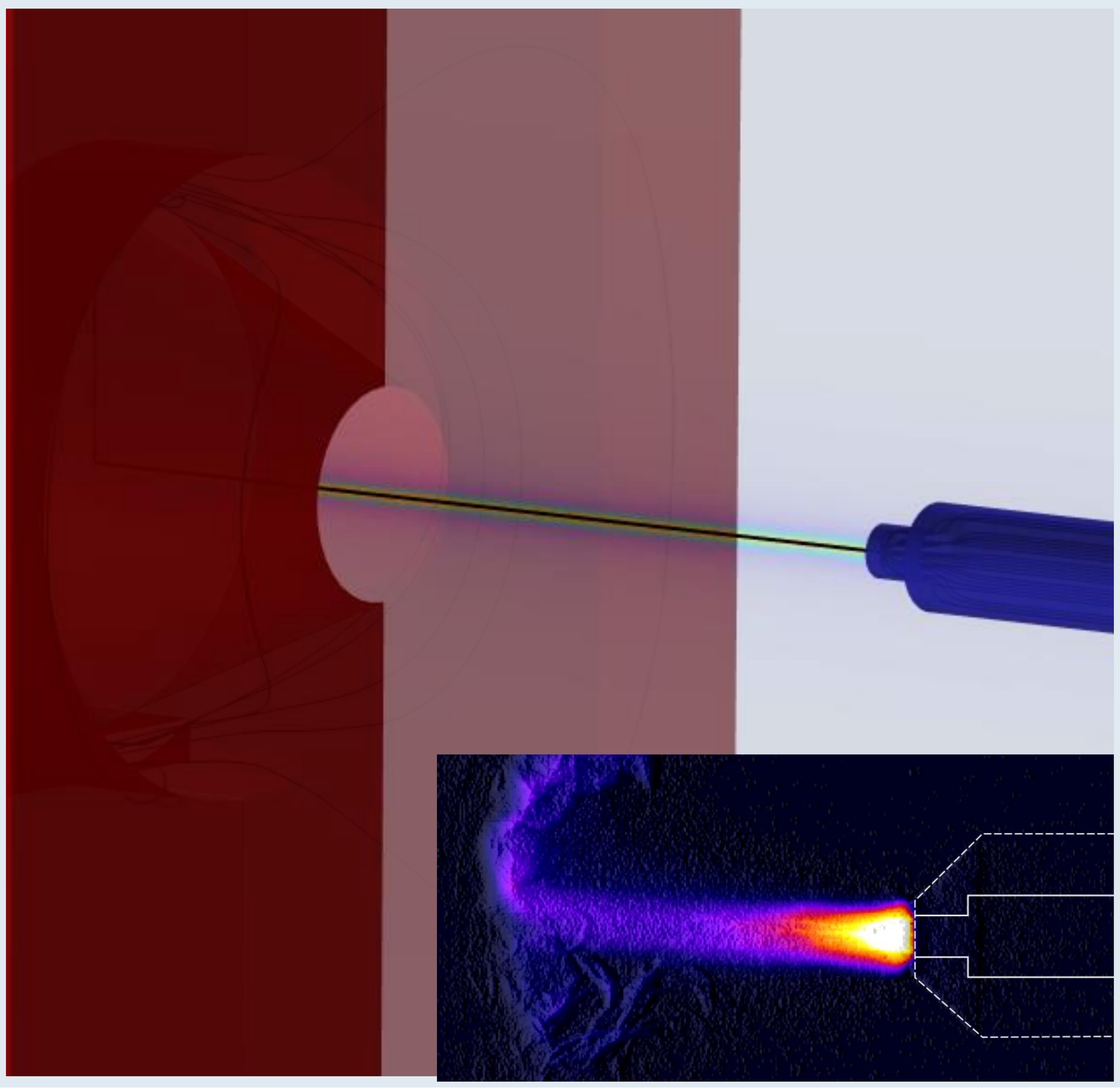

Formation of Electric Arcs by Explosive Boiling of Thin Cu Wires

Electric arcs are used in a large variety of switches that include light switches, contactors as well as low and medium-voltage circuit breakers. Here, we investigate the phenomena leading to the ignition of these arcs.

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Introduction

In the presence of a short circuit, the contacts of short-circuit current breakers heat up, and a bridge of molten metal with diameter d of about 0.1 mm forms between the electrical contacts. The contacts separation leads to the explosion of the molten bridge and to the ignition of an electric arc, which the circuit breaker must extinguish (Ref. 1).

To clarify the phenomena leading to the arc ignition, we have studied with experiments and simulations the explosion of Cu wires. Wires with d = 0.127 and 0.3 mm are placed between 2 electrodes (Fig. 1a). Linearly increasing currents with di/dt up to 10 kA/ms are obtained by the discharge of a bank of capacitors mounted in series with the test object and additional inductances (Fig. 1b).

The high current leads to the wire explosion and to a voltage peak of a few kV (Fig. 1c). After this peak, the electric arc is established and the voltage decreases down to 0.1 kV.

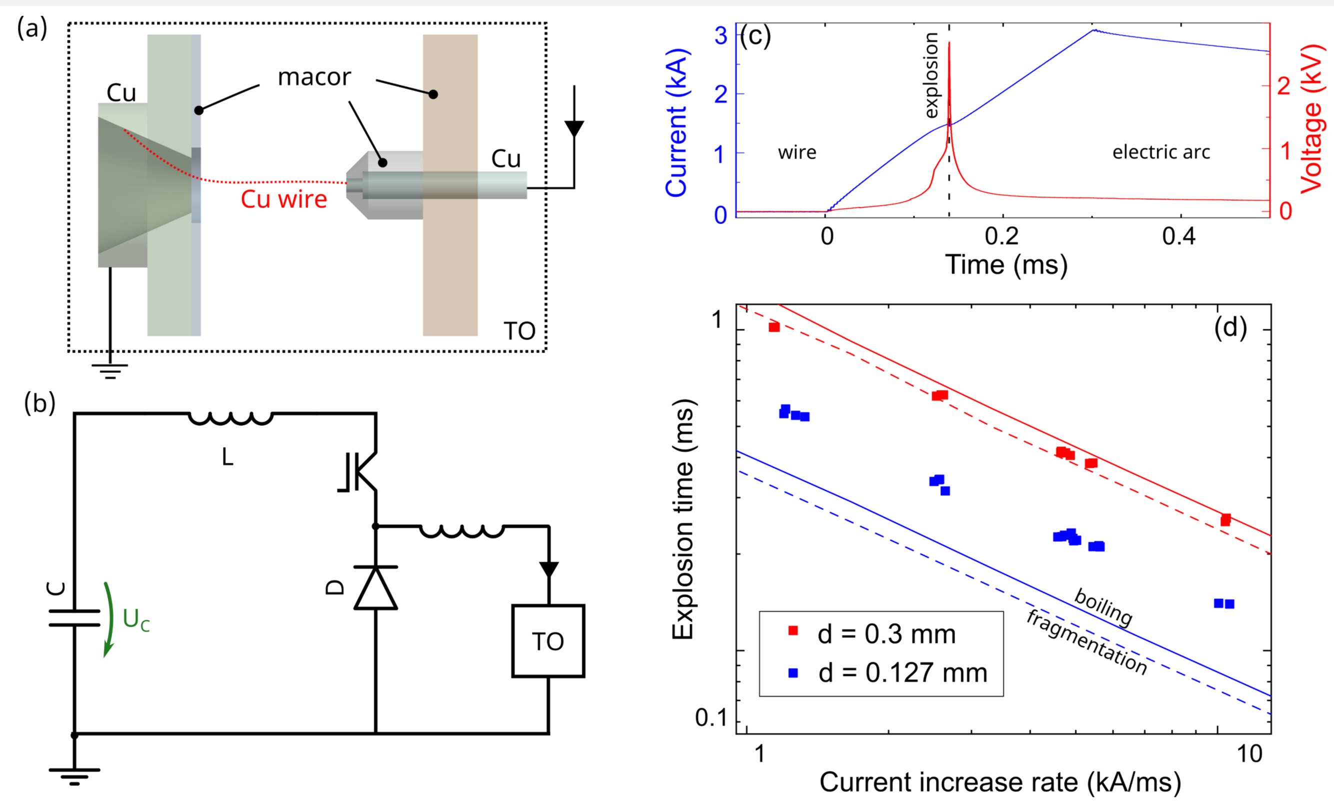

FIGURE 1. (a) Test object and (b) electrical circuit. (c) i and V measured with d = 0.127 mm and U_c = 2 kV. (d) Measured and simulated explosion times as a function of di/dt (symbols and lines, respectively).

Methodology

We compute the temperature T of the wire during the capacitor discharge test. The wire is treated as a rigid cylinder with a diameter d. Temperature-dependent material properties are used.

The thermal conductivity λ of Cu is obtained by the Wiedemann-Franz relation: $\lambda = Lo\ \sigma\ T$, with Lo the Lorenz number. We account for convective and radiative cooling, as well as for heat conduction to the electrodes.

The time-dependence of the current i is computed with an ODE that accounts for the capacitance, the resistance and the inductance of the circuit as well as for the voltage V built up by the wire.

Results

With increasing i, T and the wire resistivity rapidly increase, leading to an increase in V. With di/dt = 6.4 kA/ms and d = 0.3 mm, melting and boiling temperatures are reached after 0.31 and 0.36 ms (Fig. 2).

The magnetic pressure arising from magnetic pinch forces is $\Delta P = \mu_0 I^2/(4\pi^2 R^2)$. We assume that these forces can crush the liquid Cu wire when $\Delta P > 100\kappa_0/R$ (Ref. 2), with κ_0 = 1.306 N.m the surface tension of liquid Cu at 1400 K (Ref. 3). Thus, we conclude that the arc forms before boiling as a result of wire fragmentation.

We predict well the explosion time of wires with d = 0.3 mm (Fig. 1d). The explosion time is underestimated for thinner wires, which we attribute to leakage currents in ionized gas surrounding the wire.

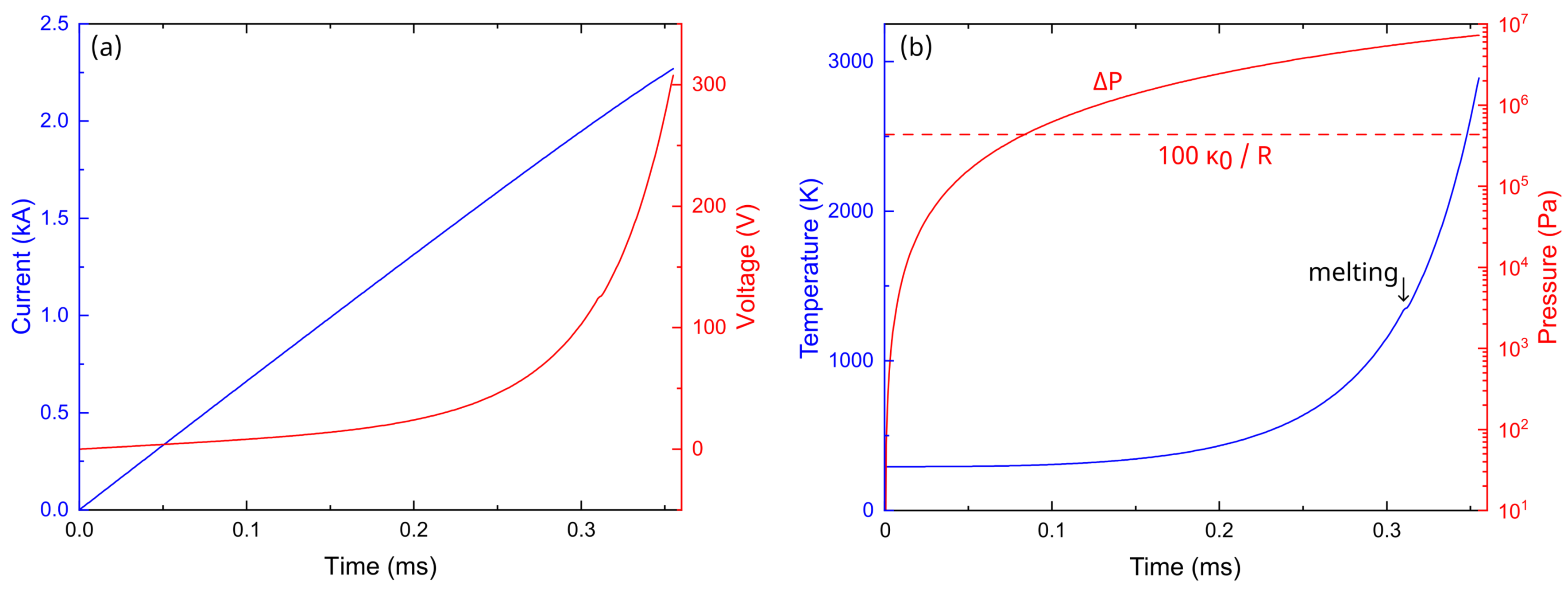

FIGURE 2. Time-dependence of (a) i and V and (b) T and of ΔP computed for the explosion of a wire with d = 0.3 mm and with U_C = 2 kV. The current increase rate is di/dt is 6.4 kA/ms.

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