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**Citation:** Jadidian, Jouya, Salman Mohseni, Morvarid Jebeli-Javan, Ehsan Hashemi, Amir Abbas Shayegani, and Kaveh Niayesh. Visualization of a Copper Wire Explosion in Atmospheric Pressure Air. IEEE Transactions on Plasma Science 39, no. 11 (November 2011): 2842-2843.

**As Published:** <http://dx.doi.org/10.1109/TPS.2011.2135381>

**Publisher:** Institute of Electrical and Electronics Engineers

**Persistent URL:** <http://hdl.handle.net/1721.1/79373>

**Version:** Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

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# Visualization of Copper Wire Explosion in Atmospheric Pressure Air

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**Abstract** - Experimental and computational images of 90 $\mu$ m thick copper wire explosion in atmospheric pressure air are presented. A Marx generator is used to produce a pulsed current density into the wire with maximum rate of rise of  $\sim 10^{20}$  A/m<sup>2</sup>s. A multiphase numerical model includes mass and momentum conservation equations, thermofield ionization, Maxwell's equations and heat transfer between phases. Visual records of experiment agree with simulation results.

**Index Terms**—Wire explosion, thermofield ionization, atmospheric pressure plasma, microjets.

**APPLICATIONS** of thin metallic wire explosion covers a broad area of technologies ranging from ultrafast fuses, detonation initiators, pulsed light sources, Z-pinch and X-pinch plasmas [1-4]. In this paper, images of a round copper wire explosion experiment in atmospheric pressure air are compared with visual simulation results. Copper wire of 90  $\mu$ m diameter is wound into a helical shape and connected as load to a Marx generator [1]. Figure 1 shows the schematic view of the experimental setup. The generated voltage pulse across the helical wire has a peak of 25 kV and 30 ns rise-time, imposes a maximum current density of  $5 \times 10^{11}$  A/m<sup>2</sup> in the wire [1]. Such a huge energy cannot be released from the wire volume; hence accumulated energy melts, evaporates and ultimately explodes the wire to supersonic plasma microjets. The di/dt stress described above, which results in the physical phase conversions from solid to plasma, have been numerically modeled. The simulations are performed in two-dimensional cylindrical geometry (assuming no variations exist in the  $\phi$ -direction). The electrical conductivity and thermal conductivity dependences on density and temperature are presumed and the ambient temperature is set to 298 K.

Heat transfer equations, i.e., conduction, convection and surface radiation are solved for the solid phase until it reaches the melting point of copper, 1357.77 K. For the liquid and

vapor (gas) phases we have solved mass and momentum conservation equations as well as the heat transfer equations.

Bidirectional phase transition criterion between liquid and vapor phases is determined based on the boiling temperature point of 2835 K and vaporization heat of  $300.4 \text{ kJmol}^{-1}$  is taken into account. The thermofield vapor ionization creates the plasma microjets, around the wire core which is itself mainly in the vapor phase [1,2]. Within the non-neutral plasma model, electron, and copper ions (i.e.,  $\text{Cu}^+$ ,  $\text{Cu}^{++}$ ,  $\text{Cu}^{+++}$ ) are described as fluids. The plasma model consists of Maxwell's equations, the Joule heating equation, conservation equations of mass and momentum for charge carrier fluids combined with heat transfer equations. The interaction of the current carrying liquid, vapor and the charge carrier fluids with magnetic field is entered into the momentum conservation equation as  $\mathbf{J} \times \mathbf{B}$  force density. Liquid flow is considered to be incompressible while vapor and plasma flow are assumed to be compressible.

Figure 2 shows the images obtained from the simulations (parts a and b) and experiment (c) at the time the current reaches its maximum value.

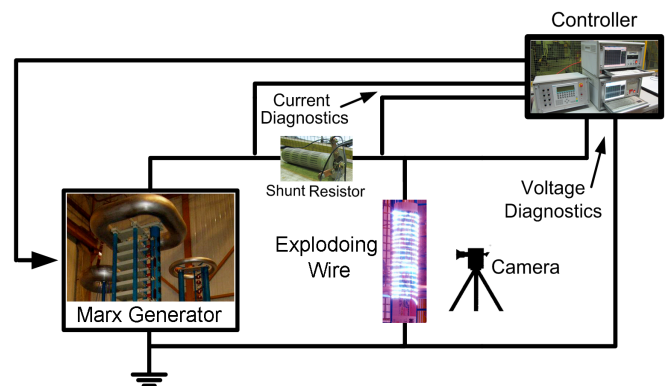


Fig. 1: Configuration of the experiment setup consisting with Marx generator, current and voltage measurement tools, high speed and helical exploding wire.

Manuscript received 1 December 2010.

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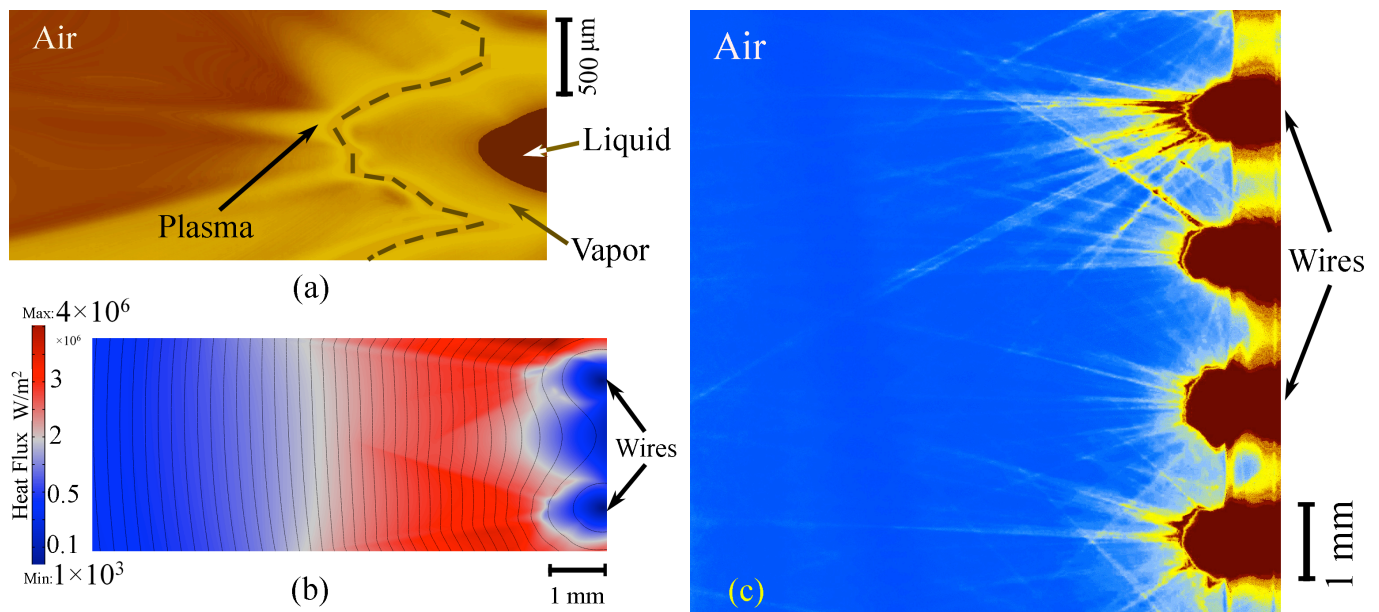


Fig. 2. Visualization of copper wire explosion phenomena for time at which the maximum current passes through the wires: (a): Simulation results for density of liquid (constant), vapor and average density of positive ions (slightly smaller than average vapor density). Separations between liquid-vapor-plasma phases are clearly marked, (b): Heat transfer between exploding wires and ambient, (c): Experimental image of exploding wires at current density of  $1.81 \times 10^{11}$  A/m<sup>2</sup>.

Simulation results revealed that most of the high speed microjet volume which is formed around the exploded wire consists of ionized copper vapor (Fig.2, part (a)). Also comparing parts (a) and (c) confirms that the bright region of the exploding wire volume is mainly occupied by the copper vapor. Comparing experimental and numerical of Figure 2, proves that the numerical model accurately predicts the formation of microjet plasmas. Figure 2 (b) shows that the majority of heat transfer occurs in the plasma region where the maximum total heat flux (~several MW/m<sup>2</sup>) is transferred between the exploding wire and ambient air. Contours in Fig. 2 (b) show the equal temperature surfaces (maximum at plasma region). In Fig. 2 (c), the red color (dark color close to the wires) identifies the most intense light emission while the blue color demonstrates the weakest light radiation. The microjets propagating away from the exploding wire core can be recognized in both experimentally and computationally generated images. The experiments confirm simulation results of microjets with average velocity to be  $1.12 \times 10^3$  m/s when the current reaches its maximum value. The velocity of microjets significantly decreases farther than 8 mm from wire core. Also, there is a narrow layer (~100 μm) between the

vapor and plasma phases in both experimental and simulation results. Most of the thermofield ionizations occurred at these slightly dark layers (Fig. 2 (a) and (c)). The results of the model for 25 μm copper wire explosion in air are also in good accordance with experimental results which are presented in [4].

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