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Abstract – **A ring cathode for a pulsed, high-current, multi-spot cathodic arc discharge was placed inside a pulsed magnetic solenoid. Photography is used to evaluate the plasma distribution. The plasma appears hollow for cathode positions close the center of the solenoid, and it is guided closer to the axis when the cathode is away from the center.**

Dense plasma is needed in a solenoid to neutralize the space-charge of a high current, pulsed ion beam: a necessary condition for compressing and focusing the beam [1] to heat a small target volume to warm dense matter conditions, for either fundamental studies [2] or for heavy ion inertial fusion [3]. In a much more detailed companion paper submitted to the same journal, we outlined the motivation, the production of plasma, and various plasma diagnostics schemes including Langmuir probes and emission spectroscopy [4]. Here we present selected photographs that give additional insight into the plasma distribution and behavior for the given geometry, and discharge and magnetic field conditions.

The final focusing solenoid is an epoxy-cast copper coil surrounding a stainless steel tube which is part of the vacuum system and which also serves as the anode of the arc discharge (Fig. 1). The solenoid is powered by a large capacitor. The peak magnetic induction reaches 3 Tesla and is approximately constant during the arc pulse of 140 µs. The arc was triggered at about the peak of the solenoid current by applying a negative voltage to the copper cathode ring. Arc spots start from initial "hot spots" that form by current flow through a metallization of the ceramic tube separating cathode and anode ("triggerless" arc initiation) [5].

Copper plasma was produced at cathode spots. The plasma density near a spot is approximately 10^{20} m^{-3} and drops off as the plasma travels way from the spots. The number of arc spots depends on the arc current, the cathode surface conditions, and other factors. The present experiment was of low repetition rate: only 1 pulse was fired every 10 s. Under these conditions, the arc tends to operate with numerous (perhaps hundreds) "type 1" spots [5].

Due to the strong magnetization of the electrons in the magnetic field, the electron motion is bound – in a first approximation – to the magnetic field line that intersects the cathode spot from which the electron was emitted. The local plasma as a whole tends to move along the field line due to electron-ion interaction. At very high field strengths, for 1 Tesla and greater, ion magnetization starts playing role too since the ion gyration radius is then typically in the millimeter range.

Depending on the position of the cathode ring, the plasma arches in a distinct way before hitting the anode (*cf.* Fig. 1). When the cathode ring is close to the solenoid center, no plasma can reach the region near the axis (Fig. 2, top). As the cathode ring is moved away from the center, the spots intersect field lines that go closer to the axis, and so plasma is brought closer to the axis: the plasma appears less and less "hollow" as the distance *d* is increased (Fig. 2).

In Fig. 3 we show a photograph that was selected for its interesting swirl near the axis. It is not obvious whether this apparent azimuthal plasma rotation is a finite ion gyration effect, or due to $\mathbf{E}\times\mathbf{B}$ or other drifts that may well be present. Further research is needed to clarify this point.

In conclusion, we have shown that photography of the pulsed plasma provides immediate insight into the spatial distribution of plasma. A first approximation optimization of the cathode position is possible based on photographs.

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Figure Captions

Fig. 1. Simplified schematic of the experimental setup. A conventional digital SRL camera (15 megapixel CMOS detector) was used to capture the image of a multi-cathode-spot discharge in a 3-Tesla solenoid. More details are described in the text.

Fig. 2. Plasma in the solenoid for various positions of the cathode ring, where the distance d is measured from the center of the 6 cm long solenoid, as indicated in Fig. 1; arc current 4.5 kA, 140 μs long, with B = 3 T.

Fig. 3. Photograph of plasma indicating plasma rotation near the axis (cathode ring 2 cm from solenoid center, B = 3 T, arc 4500 A for 140 μs).

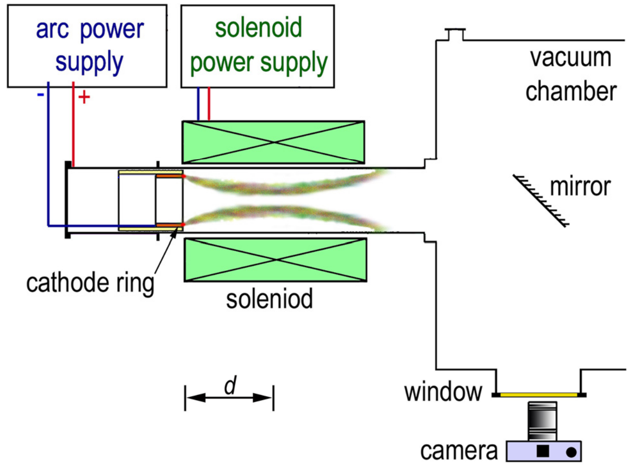
arc power
supply
-
+
solenoid
power supply
vacuum
chamber
mirror
cathode ring
soleniod
d
window
camera

Fig. 1.

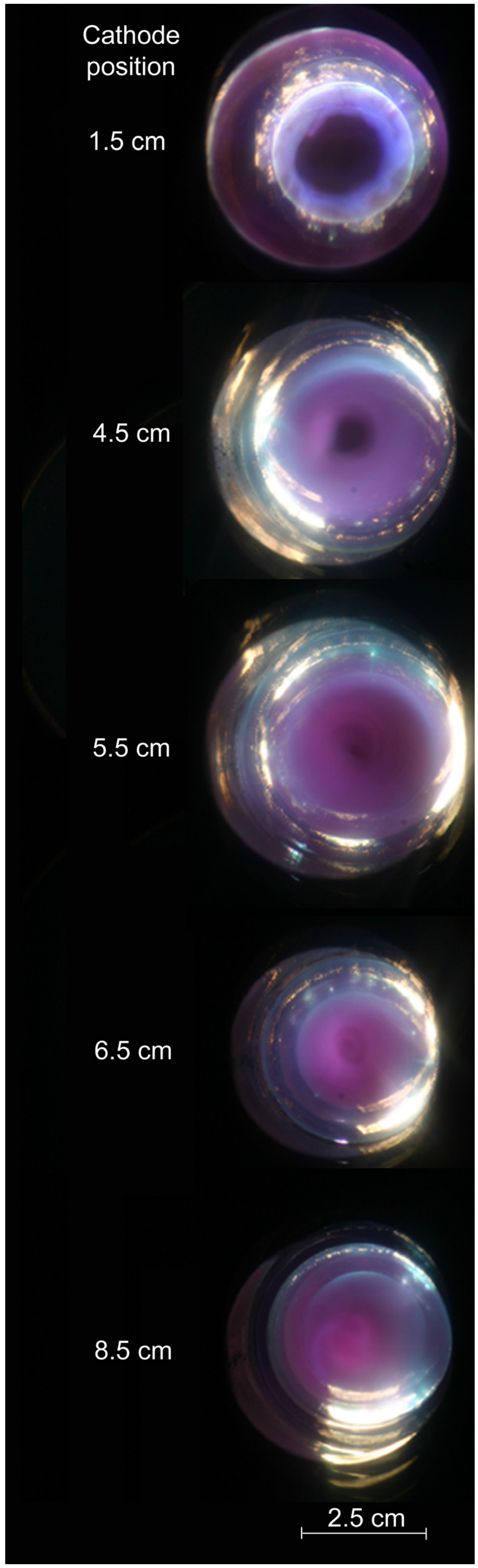

Fig. 2.

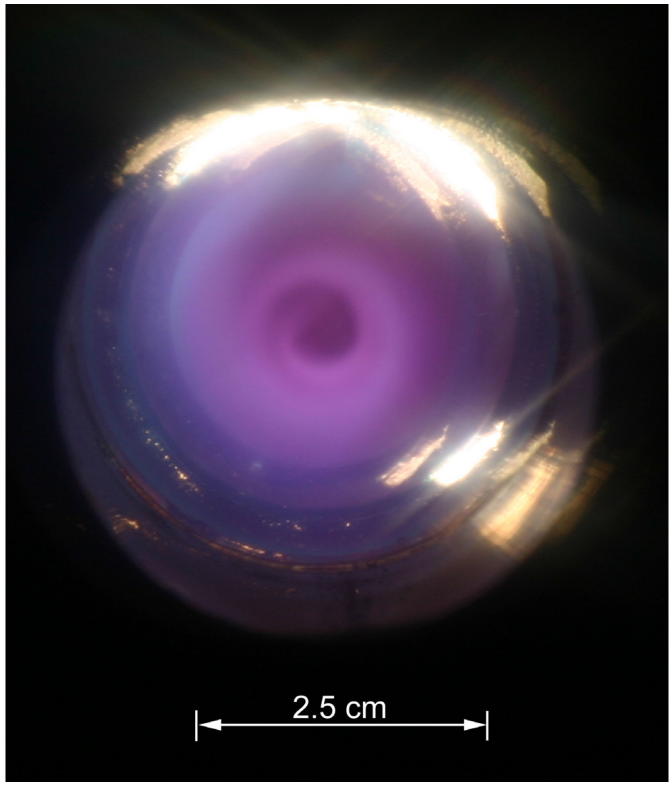

Fig. 3.