Time-resolved broadband optical absorption spectroscopy of Cr metallic vapor using an LED lightsource

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In this work, we show the feasibility of applying time-resolved broadband optical absorption spectroscopy using an LED light-source as a valuable diagnostic tool for characterizing the electrical arc during AC current switching. With our setup we have shown the capability of following in a single measurement the time-evolution of the diffusion of Chromium neutral atoms around and after current zero of an electrical arc that was ignited between two CuCr contacts. This is achieved by analyzing the absorption spectrum of Cr I resonance lines near the central wavelength of the broadband LED in the blue at 425nm, and using the so-called fast kinetics acquisition mode of the spectrometer, with a time-resolution of 415 µs.

Switching devices in power distribution networks serve as interrupters of short-circuit or overload currents. To improve their performance theoretical and experimental work related to the plasma that forms inside them is apparently necessary. Experimentally, the most straightforward measurements entail electrical recordings (voltage and current) of the arc; however optical measurements can also be conducted additionally, either by using the self-emission of the plasma or an external light source. Due to the unstable behavior of the arc (in time and space) in switching devices, it is cumbersome to characterize them, especially after current zero (CZ). After CZ namely, the self-emission of the arc plasma ceases, and thus the usage of absorption spectroscopy becomes relevant.

In low-voltage (LV) switching devices, the arc is ignited in air and is composed mostly of the evaporated contact material (Cu, Ag, Fe) [1]. In medium-voltage vacuum switching devices on the other hand, CuCr contacts are commonly used due to this material combination's capability of breaking high currents [2-3]. In our experimental investigation we used the same LV setup (arc burning in air and current level in the few kA range) but using CuCr (25% Cr-content) as contact material. Therefore, an air arc plasma that is dominated by Cu and Cr metallic vapor is expected.

The experimental conditions described above thus were conducive to verifying the feasibility of broadband absorption spectroscopy on Cr atoms using an LED light source as a diagnostic tool. The broadband LED's central emission wavelength was selected to be at 425 nm, with FWHM bandwidth of 21 nm. This spectral window allows us to observe three transition lines (emission and absorption) which are connected to the chromium ground state Cr I [3d5(6S)4s ↔ 3d5(6S)4p] @ 425.43 nm, 427.48 nm and 428.97 nm. With such diagnostic tool we have the possibilty to access the decay characteristics of the metallic vapor density after current zero.

In our experimental setup, two contacts were facing each other, with ~ 8 mm gap distance, and electrically connected (initially) with a thin Cu ignition wire. An arc is initiated after injecting a sinusoidal half-wave current of 7 ms and current peak ~ 1 - 2 kA (see Fig.1), which is obtained by discharging a capacitor bank through an RLC circuit. As for our optical setup, on the source side it consisted of a fiber-coupled LED and a collimating lens, while on the detection side it was composed of a focusing lens and an optical fiber, coupled to the spectrometer's entrance slit. The collimated light had a beam size of 20 mm, measured at the area above the arcing zone at a distance of 40 mm. The light was then spectrally dispersed using an ANDOR SR-500i spectrograph with a 600 l/mm grating and detected with an iXon EMCCD camera. The so-called fast-kinetics (FK) mode allowed us to obtain time-resolved measurements with a resolution of 415 µs and a total window of 14.5 ms. The spectral acquisition was synchronized to the electrical recording (triggered by the rise of the arc voltage). This way we could follow the time-evolution of the arc by observing first the optical self-emission of the plasma during arcing, then by following, after CZ, the resonant absorption profile of Cr atoms in the ground-state.

In Fig.2 (left), we show three cases of optical spectra at three different acquisition times; the initial LED light source profile at t = 0 ms, the superposition of LED light and the emission spectra from the arc, at t = 5.8 ms, and finally the subtraction of the absorption spectrum from the LED light at t = 9.5

ms (2.5 ms after CZ). We are interested particularly in the absorption profile of the three Cr resonance lines @ 425.43 nm, 427.48 nm and 428.97 nm and their evolution (Fig 2 right). Here we observe the absence of absorption at 434.5 nm as that corresponds to a transion between two excited states.

One emission (and absorption) peak located at 422.5nm was always observed but could not be identified. The absorption peak of this line (422.5nm) was in some cases much more pronounced.

The evolution of Cr I emission spectra, and the decay characteristics of Cr I absorption spectra thereafter, could give us an insight on the metal vapor density evolution during and after arcing. Such data can also offer precious information on the plasma gas temperature and the atoms density during the current interruption process. In the end, it can offer a way of understanding further the physics of the arc especially after CZ and a way to optimize the switching device itself.

In our investigations we carried out tests also on high Cr-content stainless-steel contacts and ignition wire. But with this material such a high broadband absorption was observed that all the LED light disappeared. We surmise that this was probably due to resonant absorption of iron lines which were situated spectrally dense to one another and with strong absorption cross-sections.

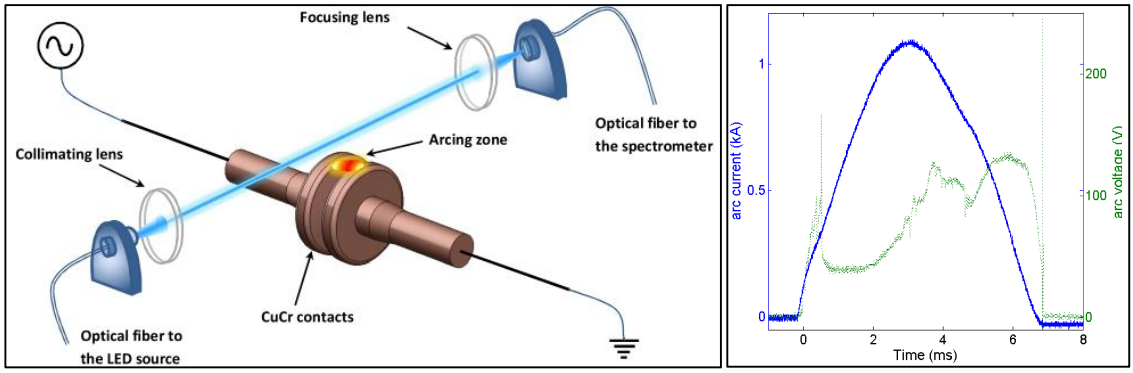

Fig. 1: Left: our experimental setup; Right: representative arc current and voltage recordings

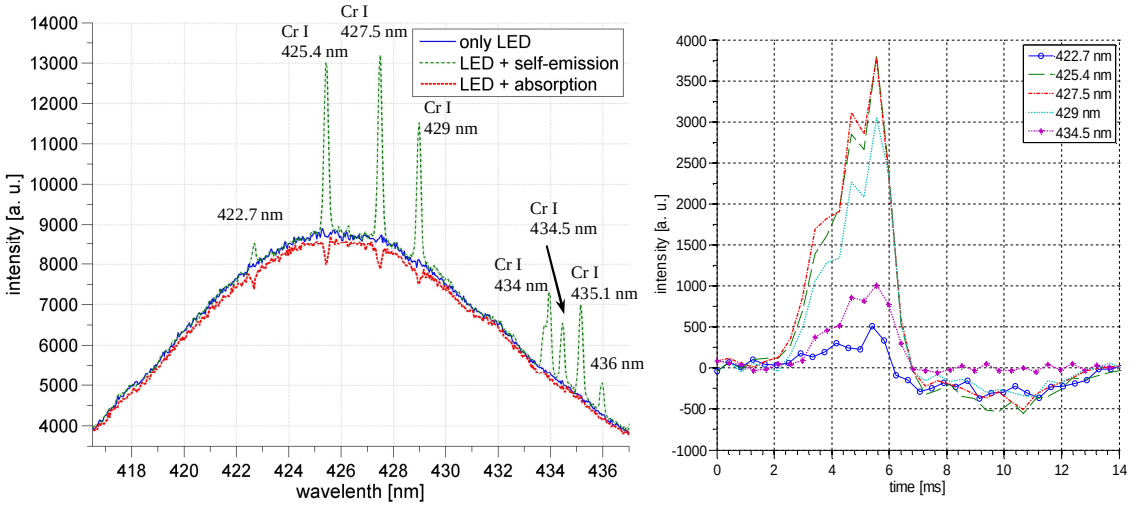

Fig. 2: Left) Three distinct cases of optical spectra: solid line shows only LED light at t = 0 ms; in dash-dotted line the self-emission of the plasma at 5.8 ms is shown; dashed line corresponds to the absorption spectrum at 9.5 ms (2.5 ms after CZ). Right) Temporal evolution of the measured main relative spectral peak intensities (emission and later absorption).

References

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