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# Application of nanosecond sparks for ignition of lean mixtures

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**Abstract:** It was found that short and intense energy release in nanosecond sparks can induce hydrodynamic motion of the gas over a long distance of the order of centimeter. The gas motion induces the transport of active species produced by plasma into the surrounding space. The present work characterizes these mentioned processes for both single and repetitive sparks under various discharge conditions.

**Keywords:** Non-equilibrium plasma, plasma-assisted combustion

## 1. Introduction

Sharp energy release in nanosecond sparks can induce hydrodynamic motion of the gas over a long distance [1,2] of the order of centimeter. The motion of the hot gas induces the transport of active species produced by plasma into the surrounding space. The maximal propagation of the hot gas filled with active species was found to be significantly larger in the case of nanosecond spark than in the case of conventional spark.

## 2. Experimental results

In order to monitor the hydrodynamic effects induced by nanosecond spark four optical diagnostics were combined: Schlieren, PLIF, fast imaging and emission spectroscopy. Figure 1 presents a simplified scheme of experimental setup. The diagnostics mentioned above were synchronized with measurements of the energy deposited in the spark [3]. As it was mentioned above sharp energy release in nanosecond sparks causes rapid hydrodynamic expansion of the gas where the discharge was initiated. Figure 2 presents the results of energy measurements for repetitive nanosecond spark initiated at different frequencies at two different distances between the electrodes: 2 and 7 mm. One can see that the energy deposited in the spark change continuously with frequency which means that the qualitative results obtained for a certain frequency can be extended for other frequencies.

As expected the crucial parameter regulating the expansion of the hot gas after the discharge is the deposited energy per millimeter of the spark. Figure 3 presents the expansion dynamics of the hot gas after a single nanosecond spark for the case when the discharge of the same energy was initiated at different distances between the electrodes: 1,2,3 and 4 mm. One can see that the size of the active medium (defined in the figure) changes in time in the same way for all the presented cases which proves the statements above.

Figure 4 presents the comparison of OH PLIF images obtained for a) nanosecond single spark of 10 ns duration;

b) conventional spark produced by AUDI coil system. The energies of the discharges are marked in the figure. It is clearly seen that the volume filled with hot gas and radicals in the case of ns discharge is larger even despite of the lower energy deposition.

In the case of a burst of nanosecond sparks the expansion of the active medium becomes even more extensive. Figure 5 presents Schlieren image obtained for a burst of 30 pulses at 70 kHz and dependence of linear size of the hot gas vs number of pulses in the burst. The energy of each pulse was 2.5 mJ.

It is seen that in the case of the burst of ns sparks with the total energy corresponding to the energy of conventional spark (54 mJ) the expansion of the hot gas is about 10 times larger than for the conventional system. Thus in the case of ns spark there is an opportunity to redistribute the same energy over larger volume. We believe that this is a promising tool for ignition of lean mixtures in turbulent flows where stability of ignition can be provided by increase of the volume affected by the discharge. It should be also noted that the considered effect may be used for development of the internal combustion engines since the scale of gas expansion is the same that the distance between the piston and endplate in the case of typical car engine.

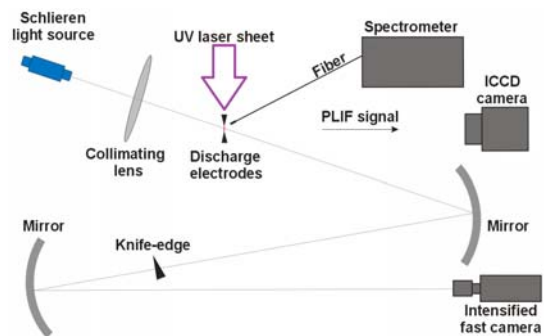


Figure 1. Experimental setup. Synchronized PLIF, Schlieren and emission spectrometry diagnostics. The focal length of the lenses for Schlieren technique is 1 m.

Both spherical mirrors have focal distance of 2 m.

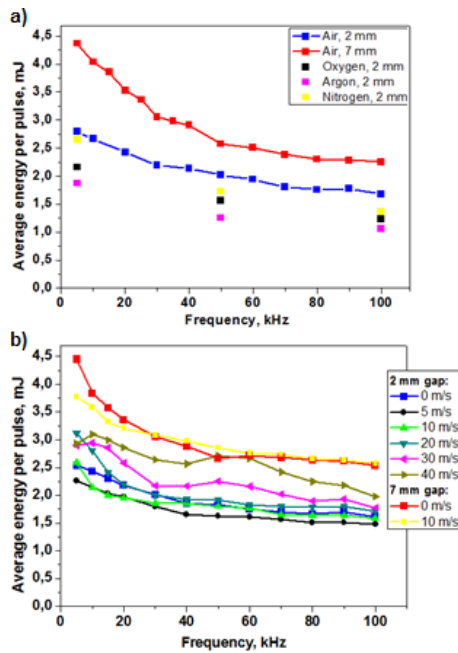


Figure 2. Average energy per pulse deposited in multiple spark at different frequencies of discharge repetition.  $P=1$  bar,  $U=30$  kV, air a) steady state gas and b) in the flow of different speed.

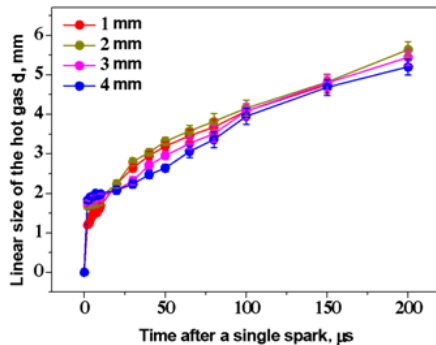


Figure 3. Dependence of the linear size of the active medium vs time after a single spark. Ambient air,  $U=30$  kV, 10 ns duration. The distance between pin-to-pin electrodes was 1,2,3 and 4 mm.

### 3. Conclusions

We have shown how the energy deposited in a nanosecond spark spatially redistributes during its afterglow at sub millisecond scale. The gas heated by a thin spark channel expands with a speed  $\sim 60$  m/s for 5 mm scale during the period about 100  $\mu$ s and then slows down. The expansion of hot gas is accompanied by transport of active species produced in the plasma. It has also been demonstrated that this sharp hydrodynamic expansion is the feature on nanosecond discharges. In the case of conventional ignition system of the same deposited energy the scale of expansion is significantly

shorter.

The experiments with repetitive nanosecond sparks demonstrated that the dimension of the expanded hot gas at sub millisecond scale increases linearly with the number of repetitive pulses. This kind of discharge makes it possible to affect a large gas volume ( $>1\text{cm}^3$ ) which is promising for ignition of lean mixtures and flow control.

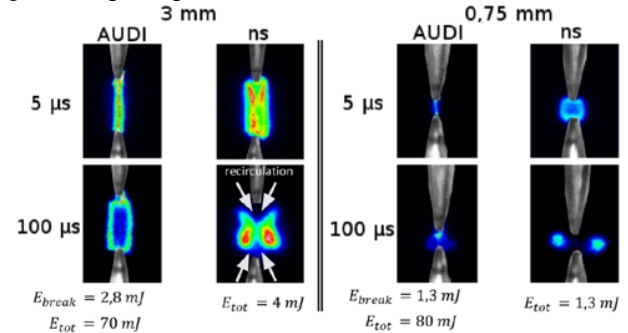


Figure 4. PLIF images comparing nanosecond single spark and a spark initiated by conventional AUDI system. Ambient air.

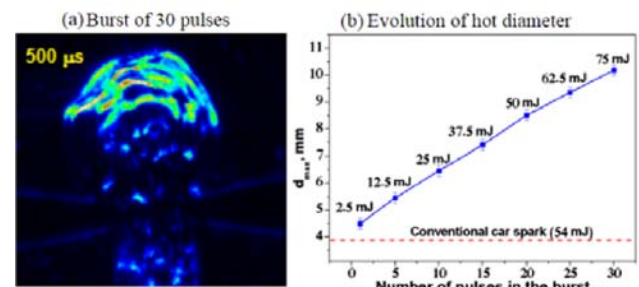


Figure 5. a) Schlieren image of a burst of 30 nanosecond sparks at 70 kHz; b) Diameter of the hot gas size vs number of ns sparks. Ambient air, 1 mm gap.

### 4. Acknowledgements

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### 5. References

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