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Initiation of electric discharges in gases by resonant laser pulses *

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We describe the method of initiation of an electric discharge in gases by a resonant laser light. It consists in the admixing of the gas of atomic vapour with characteristic absorption lines. The resonance transition is saturated by the laser pulse, and then – due to superelastic collisions between electrons and excited atoms – the heating of plasma and fast increase of its density occurs. This induces the avalanche break-down of the gas in the electric field between cathode and anode.

1. Introduction

The phenomenon of electric discharge in gases has been widely used in contemporary electronics. For example, in spark-gaps the gas break-down is applied for fast switching of high voltage and high current transitions. The electric discharge is initiated by primary electrons and ions produced with the use of additional ignition electrode or by means of pulses of ionizing radiation. In laser techniques either the electric break-down of gas by high power laser pulses or the creation of plasma by a light beam focused on the surface of the electrode or the multiphoton ionization are used as processes initiating the spark-gap switching [1]. Both methods require a high pulse energy and are not sensitive to the laser wavelength. In this paper we present a new method of initiation of discharge in gases by laser pulses. Its main feature is that the effect occurs only when the laser wavelength is tuned to one of the resonance lines of the gaseous medium.

2. Ionization method

A very efficient ionization of dense alkali vapour by intense resonant laser pulses was experimentally discovered by Lucatorto and McIrath [2], [3]. This process, well known as LIBORS (Light Ionization Based On Resonance Saturation) was theoretically predicted by Measures [4], [5] and investigated later by several groups [6]–[8]. It consists in efficient transfer of the laser pulse energy stored in excited atoms to the plasma due to superelastic collisions between these atoms and electrons.

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This effect leads to the fast heating of plasma and to the increase of its density. The process develops in avalanche way. With long (1 μm) and powerful (1 MW) laser pulses at high atom density (10^{22} m^{-3}) nearly 100% ionization was achieved [2], [3], [6], [7]. LIBORS could be observed also for lower atom concentrations (even 10^{19} m^{-3}) and less energetic laser pulses (30 kW, 6 ns FWHM time) but with lesser efficiency [8]. We used this effect to initiate electric discharges in gases.

3. Experiment

The experimental setup is presented in Figure 1. Our investigations were carried out with the help of a pyrex cell with molybdenum anode and cathode 4 cm apart. The cell was evacuated to the residual pressure 10^{-5} Pa and then filled with a few drops

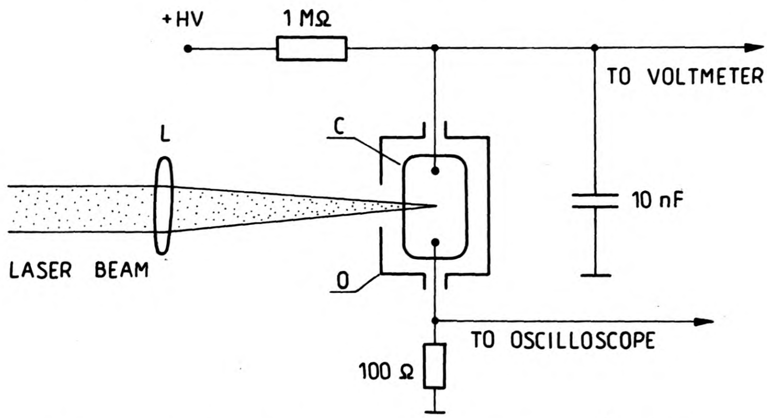

Fig. 1. Experimental setup. O — oven, C — pyrex cell, L — lens

of sodium and 300 Pa of helium. In order to protect the pyrex glass against the aggressive influence of the sodium vapour the $Na_2B_4O_7$ wall coating was used [9]. The cell was placed in the oven. A nitrogen-laser-pumped rhodamine 6G dye laser was used as a light source. The FWHM time of the laser pulse was 6 ns; the line width was less than 0.1 nm. The laser beam was focused between the anode and cathode by a lens of 30 cm focal length. Current pulses passing across the cell were observed by means of oscilloscope.

4. Results

In order to achieve the triggering of electric discharges by resonant laser pulses the voltage applied to the cell should be about 20–70 V lower than that inducing an autobreak-down of gas. The voltage 280 V was used. The minimum sodium vapour density should be greater than 8×10^{18} m^{-3} in order to achieve sufficient LIBORS efficiency.

In the conditions described above, laser shots induce strong current pulses which are the result of the avalanche ionization of the gas in the electric field between anode and cathode initiated by LIBORS. The pulse duration is determined by the time of discharge of the capacitor. For 300 Pa of helium the pulses were 20 ms long and were delayed by 20 μm with respect to the laser shots. Both time-durations decrease with the buffer gas pressure increment. This is related to the time needed for the development of the discharge avalanche and to the final plasma density. For example, at 200 Pa of the buffer gas the delay time was equal to 0.2 μs and the pulse duration was 40 μs. Higher buffer gas pressures could not be used because the LIBORS process would be strongly reduced [10].

The process occurs for quite low energies of the light pulses. The electric discharge in our case could not be induced by surface processes, i.e., when the laser beam is focused on the electrode or on the cell wall even for the pulse power as high as 50 kW but with the wavelength detuned from the resonance. On the other hand, with the laser wavelength tuned to the D_1 or D_2 line, we observe the triggering effect for the laser power as low as 300 W (1.8×10^{-6} J). For such a low power the LIBORS signal could not be observed directly using Langmuir probe method [8]. The low threshold of the process leads to the conclusion that the laser-induced multiphoton ionization probably does not play any role in our experiment.

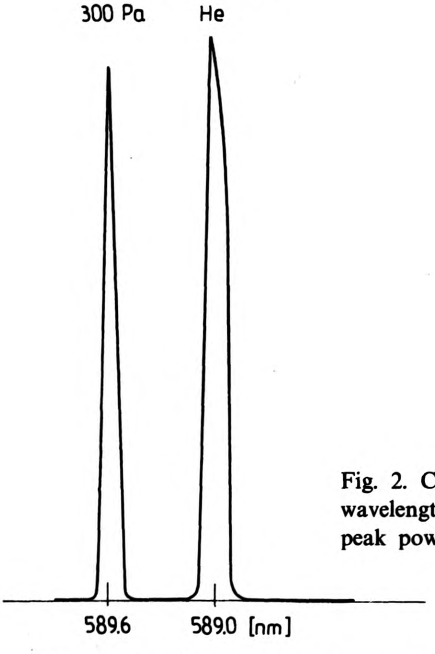

Fig. 2. Current pulses amplitude (a.u.) as a function of the laser wavelength for sodium vapour density 10^{19} m^{-3} and the laser pulse peak power 400 W

Figure 2 shows the spectrum of this process recorded with the use of boxcar integrator. Current pulses disappear when the laser line does not overlap with one of the sodium D lines. The spectral resolution is comparable with the laser line width. For higher buffer gas pressures the selectivity decreases. For 200 Torr of buffer gas the components of sodium doublet cannot be resolved.

The effect described in this paper can be applied to the calibration of a tunable laser wavelength. Cesium and rubidium vapours or their mixture seem to be a good candidate for it because of a large number of resonance lines in the visible spectral range and high vapour pressure at relatively low temperature of the cells.

References

[1] KACHEN G., STEINMETZ L., KYSILKA J., Appl. Phys. Lett. **13** (1968), 229.
[2] LUCATORTO T. B., MCIRATH T. J., Phys. Rev. Lett. **37** (1976), 428.
[3] MCIRATH T. J., LUCATORTO T. B., Phys. Rev. Lett. **38** (1977), 1390.
[4] MEASURES R. M., J. Quant. Spectrosc. Radiat. Transfer **10** (1970), 107.
[5] MEASURES R. M., CARDINAL P. G., Phys. Rev. A **23** (1981), 804.
[6] ROUSSEL F., BERGER P., SPIESS G., MANUS C., GELTMAN S., J. Phys. B: Atom. Molec. Phys. **13** (1980), L631.
[7] SKINNER C. H., J. Phys. B: Atom. Molec. Phys. **13** (1980), 55.
[8] STACEWICZ T., Opt. Commun. **35** (1980), 239.
[9] STACEWICZ T., KRASIŃSKI J., J. Phys. E: Sci. Instrum. **16** (1983), 1028.
[10] STACEWICZ T., KRASIŃSKI J., Opt. Commun. **39** (1981), 35.

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Возбуждение газовых разрядов резонансными лазерными импульсами

Описано метод газовых разрядов лазерным светом с резонансной частотой. Он заключается в легировании газа атомными парами с характеристическими абсорбционными линиями. Резонансный переход насыщен лазерным импульсом и тогда вследствие суперэластических столкновений между электронами и возбужденными атомами происходит нагрев плазмы и быстрой рост ее плотности. Это вызывает лавинный пробой в газе в электрическом поле между катодом и анодом.