Indian J. Phys. **66B** (5 & 6), 549 – 554 (1992)

Laser induced gas breakdown : a possible fast plasma switch

R K Thareja

Department of Physics and Centre for Laser Technology,
Indian Institute of Technology, Kanpur-208 016, Uttar Pradesh, India

Abstract : A review of on laser induced gas breakdown using only laser beam, a laser beam and static electric field, the effect of laser produced plasma from a biased metal target in a background gas is reported. We report that switching of gas discharge is controlled by metal plasma or polarity of the target

Keywords : Lasers, gas breakdown, plasma switch

PACS Nos. : 52.50 Jm, 52.75 kq

1. Introduction

Since the first report of laser induced breakdown [1] of air in 1963, there has been an enormous growth of understanding of the phenomenon [2,4]. By focusing a laser beam in gas it is possible to obtain a high-temperature, high density plasma. Various properties of the gaseous plasma created by focusing laser radiation have also been studied. Laser produced plasmas have been used as source for high intensity X-rays [5] and VUV continuum in rare gases [6]. Sensitive techniques to measure UV radiation using gas breakdown have also been developed [7]. Lasers have been used to trigger electrical discharge between electrodes in vacuum and in gases in spark gap switches [8]. Pendleton and Guenther reported on the initiation of the breakdown by a laser at point in the inter electrode space between a gap or one of the two electrodes. The laser produced plasma consequently electrically closes the gap. The effect has been utilized for laser trigger switching (LTS).

Detailed calculations of the gas breakdown threshold caused by laser irradiation have been carried out by Kroll and Watson [9]. Buscher *et al* [10] were the first to study the breakdown threshold intensity of rare gases at wavelengths 1.06, 0.69, 0.53 and 0.35 μm. They found that the threshold intensity for each rare gas studied, first increases to a maximum and then decreases with decreasing wavelength. Alcock *et al* [11] reported the breakdown of nitrogen, methane and rare gases using a ruby laser of pulse width 20 ns and its second harmonic, in agreement with Buscher *et al* [10]. Krasyuk *et al* [12] studied the breakdown threshold of nitrogen, helium and argon using ps pulses of ruby laser in the pressure range

$2 \leq p \leq 10^4$ Torr. The results show a weak dependence on the pressure for $p \leq 10^3$ Torr in He and Ar and $p \leq 300$ Torr in N_2, characteristic of multi photon absorption. At higher pressure in He and Ar there is a pronounced pressure dependence, indicating the occurrence of collisional ionization by inverse bremsstrahlung absorption, however for N_2 the pressure dependence is less pronounced. Gamal and Harith [13] and Weyl and Rosen [14] have done theoretical calculations of laser induced breakdown thresholds of atomic molecular gases as a function of pressure of the gas, pulse width of laser, using the equation of growth of electrons, and including the effects of both multi photon and cascade ionization.

Simultaneously, there have been reports on the gas breakdown by focusing laser radiation in the presence of transverse static electric field [15]. The interaction of laser beam with the target depends on the characteristics of the target material and laser beam both. For low irradiation ($\approx 10^6$ W/cm^2), the absorbed radiation appears as heat which is slowly distributed through out the material by thermal diffusion. Further increase in irradiation results in vaporization of the target material. At still higher power densities $\approx 10^8$ W/cm^2, it is possible to produce plasma directly at the focus of the target without going through the intermediate stepes [16,17]. It has been observed that the presence of a metallic target reduces the threshold intensity for breakdown for gases. Bondarenko *et al* [18] reported breakdown of air at the surface of the metals using low power CO_2 laser and explained on the basis of thermal process which accompany optical breakdown. Danshchikov *et al* [19] observed that the presence of a precursor plasma decreases the threshold intensity for breakdown of inert and molecular gases. Short wavelength radiation emitted form the metal plasma was also found to reduce the threshold intensity for breakdown of the gas [20,21].

In the present talk, I will review the work done on laser induced gas breakdown using only laser beam [22,23], in the presence of static electric field [24], the effect of metallic target on breakdown [25] of gases and discuss a possible application of laser induced gas breakdown near metal surface to fast switching [26].

2. Experimental setup

To study air breakdown using Nd : YAG laser and its harmonics, a Nd : YAG laser (DCR-4, Spectra physics) with Gausssian limited mode structure delivering 900 mJ in 2.5 ns (FWHM) at fundamental with a repetition rate of 10 pps, was focused with a quartz lens (f=12 cm) in to the centre of a vacuum chamber. The chamber was evacuated to < 10^{-2} Torr with a rotary pump. Laser energy was varied by varying the voltage on the laser amplifier. No significant variation in mode pattern was observed at different energies. The energy of the laser was measured with a laser power meter (Ophir Model No. 30A), by placing the power meter in the path of the main beam. The output power of the laser was stable within ±7%. The beam divergence being less than 0.5 m rad. Threshold energy was measured only when the breakdown spark, seen visually through the window, was modulated at 10 pps. Breakdown spot size was recorded using a camera.

3. Results and discussion

Figure 1 exhibits the dependence of threshold intensity on wavelength of laser radiation at different pressures of air.

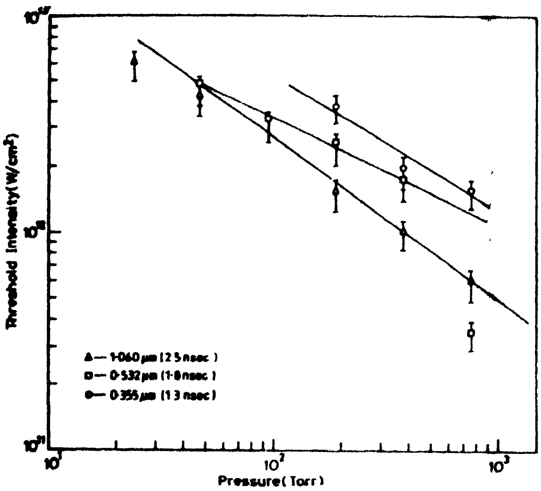

Figure 1. Dependence of threshold intensity on wavelength of laser radiation at different pressures of air.

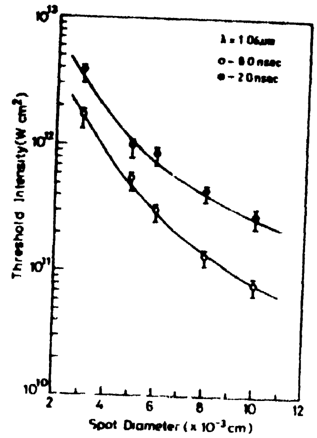

Figure 2. Variation of breakdown field for various focal spots and pulse widths of laser

Breakdown threshold intensity of air at 1.06 μm shows a pronounced pressure dependence, characteristic of collisional ionization by inverse bremsstrahlung absorption. The threshold intensity scales with pressure as $P^{-0.8}$. However, weak dependence on pressure, $P^{-0.4}$ is observed at 0.532 and 0.355 μm indicating the occurrence of multi photon absorption. Thus breakdown of air at visible and shorter wavelengths may be initiated with photon absorption and then proceed due to cascade processes. A systematic study was under taken to investigate the effect of spot size, pulse width on breakdown of air using 0.226, 0.355, 0.532 and 1.06 μm irradiation. Figure 2 shows the variation of breakdown field for various focal spots pulse widths of laser. It is observed threshold electric field varies as $t_p^{-0.5}$ for 0.532, 0.355 and 0.266 μm irradiation and $t_p^{-0.35}$ for 1.06 μm irradiation.

In order to look for practical application of laser induced gas breakdown we looked for breakdown of Ne, Xe and Ar gases at various pressures using a low power laser XeCl (308 nm) in the presence of transverse static electric field. We observe that the number of photons actually involved K_0 to ionize the gas depends on bias voltage; with the increase of bias voltage the value of K_0 decreases. We continued investigation to look for the effect of a metallic target, Cu in our case, on the threshold laser energy for breakdown of the argon gas.

Experimental arrangement is similar to that of one used earlier. It consists of a specially designed glass cell having two parallel brass plates (20 × 25 mm²) separated by 6.5 mm and a copper target at a distance of 15 mm from the edge of the parallel plates. The cell was evacuated to a pressure of < 10^{-4} torr and then filled in with argon gas at a pressure of 8 torr. A bright green metal plasma is observed by focusing (f=12 cm) an XeCl (308 nm) excimer laser, delivering 3.5 mJ in 25ns at 10 pps, on to the copper target. The best focusing of the laser radiation on to the copper target is defined as $x = 0$. The irradiation on to the target and hence the extent, size of plasma is reduced by moving the lens away from the copper target on the same optic axis. Copper target is biased positive or negative w.r.t. brass plate using an EG & G power supply (3.0 kV, 10 mA).

In the following we describe the effect of metal plasma on laser induced breakdown of argon gas in various configuration of biased target an plate . Static glow discharge of argon gas was observed when a static voltage of 0.58 kV was applied between the target and plate; however, when laser radiation is focused or defocussed, depending on the polarity of the target as shown in Figure 3 - 6, pulsed glow discharge modulating at 10 pps was observed with static voltage of 0.32 kV. Breakdown of argon gas was observed visually by the appearance of glow discharge modulating at 10 pps.

Case 1 :

Static voltage is applied across plate (+ve) and target (ground) as shown in Figures 3a and 3b. We observed pulsed discharge in the region between plate and target only in the

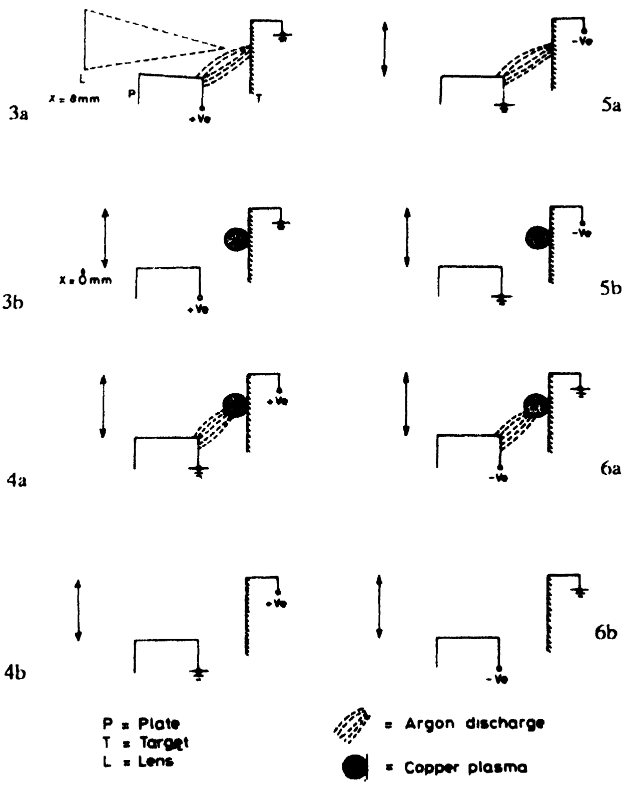

Figure 3 – 6. Various configurations for plasma switch.

configuration of Figure 3a when laser is defocussed by 8 mm. At this position copper plasma was not visible and only source of initiating breakdown is the photo electron emitted from the copper surface. The emitted electrons gain enough energy in the static field and ionize the argon gas by inelastic collisions leading to quick bridging of the gap. However, when laser radiation is focused on to the copper target a bright green plasma appears and argon discharge disappears as shown in Figure 3b. The electrons are attracted towards the +ve plate and a sheath is formed at a distance of λ_D, debye length (in mks units) given by

$$\lambda_D = \left(\frac{e_0 K T_e}{n_e e^2}\right)^{\frac{1}{2}} \quad \text{meter}$$

Even if we assume minimum electron density, $n_e \simeq 10^{15}$ m t^{-3} and temperature, $T_e \simeq 0.8$ eV, debye length is 210 mm. Thus positive potential is screened off beyond 210 mm and argon discharge disappears.

Case 2:

Static voltage is applied across target (+ve) and plate (ground) as shown in Figures 4a and 4b. Unlike Case 1, here we observe argon discharge only in the presence of copper plasma as shown in Figure 4a. The effect of plasma is essentially to shift the position of positive potential by a distance equal to the size of plasma, $\simeq$ 7 mm. This results in decrease in the virtual distance between target and plate and hence increase in electric field resulting in breakdown of argon gas. However, if the laser radiation is defocussed by 8 mm as shown in Figure 4b, the argon discharge disappears.

Case 3:

Static voltage is applied across plate (ground) and target (-ve) as shown in Figures 5a and 5b. Argon discharge appears only when laser is defocussed by 8 mm as shown in Figure 5a, Situation is identical to Figure 3a, target being at lower potential than the plate, photoelectrons emitted from target surface are accelerated towards the plate to gain energy and ionize the argon gas by inelastic collision. However, with focused laser radiation as shown in Figure 5b, we have situation similar to Figure 3b where sheath formation prevents the argon discharge.

Case 4:

Static voltage is applied across target (ground) and plate (-ve) as shown in Figures 6a and 6b The situation is opposite to Case 3 and similar to Case 2, we observe argon discharge with focussed laser radiation which disappears by defocussing the radiation.

In conclusion, we observe that ionization or argon gas can be switched ON or OFF either keeping laser focusing conditions fixed and by changing the polarity or keeping the polarity fixed and by changing the laser radiation from focused to defocussed state.

Acknowledgments

Collaboration with Dr V Kumar, Mr D V S Muthu and Ms R Tambey is highly acknowledged. Work is partly supported by Department of Science and Technology, New Delhi.

References

[1] P D Maker, R W Terhune and C M Savnge *Proc. Third Int. Conf. Quant. Elect.* (Columbia, New York) eds P Grivet and N Bloembergen p 1559

[2] C Grey Morgan 1975 *Rep Prog. Phys.* **38** 621

[3] P Agostini and G Petite 1988 *Contemop Phys.* **29** 57

[4] E T Kennedy 1984 *Contemp. Phys* **25** 31

[5] C M Brown, J O Ekberg, U Feldman and J E Seely 1987 *J Opt. Soc Am.* **84** 533

[6] P Laporte, N Damany and H Damany 1987 *Opt Lett* **12** 987

[7] N S Kopeika, R Gellman and A P Kushepevky 1977 *Appl Opt.* **16** 2470

[8] A H Guenther and J K Bettis 1987 *J Phys* **D11** 1577

[9] N Kroll and K M Watson 1972 *Phys Rev* **A5** 1883

[10] H Buscher, R Thomlinsen and E Damon 1965 *Phys Rev Lett* **15** 847

[11] A Alcock, K Kahn and M Richardson 1972 *Opt Commun.* **6** 342

[12] P N Krasyuk, P P Pashinin and A M Prokhorov 1970 *Sovt. Phys JETP* **31** 860

[13] Y Gamal and M Harith 1981 *J Phys.* **14** 2209

[14] G Weyl and D Rosen 1985 *Phys Rev* **A31** 2300

[15] J Tulip and H Senguin 1973 *Appl Phys Lett* **23** 135

[16] K Kagawa ans S Yokoi 1982, *Spectrochim Acta* **B37**, 789

[17] V Kumar and R K Thareja 1988 *Bull Am Phys. Soc* **33** 1653

[18] A V Bondarenko, V S Golubev, E V Dan'shchikov, F V Lebedev, A A F Nastoyashchii and A V Ryazanov 1980 *Sov Phys Dokl* **25** 616

[19] E V Dan'shchikov, L A Dymshakov, F V Lebedev and A V Ryazanov 1982 *Sovt J Quant Elect.* **12** 62,67

[20] Michel G Drouet 1977 *Appl Phys Lett* **31** 647

[21] J M Green, W T S Evest and O R Wood II 1977 *J Appl Phys* **48** 2753

[22] D V S Muthu, V Kumar, R Tambey and R K Thareja 1991 *Parmana-J Phys* **37** 167

[23] R Tambay and R K Thareja 1991 *J Appl Phys* **70** 2980

[24] V Kumar and R K Tharrja 1988 *J. Appl Phys.* **64** 5269

[25] V Kumar and R K Thareja 1991 *Lasers and Particle Beams* **10** 109

[26] V Kumar and R K Thareja 1992 *Appl. Opt.* **31** 3460