SOME RECENT ADVANCES IN OPTICALLY CONTROLLED DISCHARGES

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Abstract

The recent increase in modular pulsed power systems has amplified the potential of optically controlled discharges where stringent synchronization or precise timing is required. This interest had led to new switching applications and concepts as well as new understanding of the switching process from a fundamental standpoint. The increasing diversity of wavelengths available has necessitated a modification of the generally accepted laser-initiated breakdown mechanism. Advances in high time resolution diagnostics techniques have as well allowed a deeper insight into heretofore conjectured mechanisms.

New understanding in optically controlled discharges and new applications since the last review (1977) will be addressed. These include the impact of short wavelength lasers, their application in opening switches including the potential of optogalvanic effects which are of particular significance in controlling diffuse discharges. One additional area of considerable promise is photoconductive switching using intrinsic solid state materials. There is no question but that the potential of optically controlled discharges is only beginning to be realized, primarily as a result of improvements in laser versatility and reliability, efficiency of interaction of the optical control energy (particularly in a resonant mode), demonstrated precise timing and synchronization capability to below a picosecond and improved understanding of the total switching event. Possibilities of optically controlled discharges not yet demonstrated will also be discussed.

Laser-Triggered Switches

Since the first report of laser-triggered switching in 1964 [1], numerous investigations on laser-initiated discharges have been performed. Laser triggering of high voltage switches employing various dielectric media is well established as a precision technique for initiating conduction. The advantageous features inherent to the laser-triggered discharge are [2]:

- Electrically uncoupled
- Suitable for remote operation
- Short and variable delay with low jitter
- Simple structure
- Reproducible, reliable, low maintenance
- RFI insensitive
- Suitable for repetitive operation
- Triggering of low voltage long gaps
- Suitable for multigap or multichannel operation
- Suitable for all types of dielectric or semiconductor media

The mechanism of laser triggering of spark gaps can take several forms:

1. The passage of the laser through the gas or its interaction at an electrode or in the dielectric can lead to a reduced pressure region tending to enhance breakdown.
2. Radiation causes the emission of charged particles from an electrode (plasma production at an electrode), producing results similar to those active in a trigatron or avalanche/streamer breakdown.
3. A laser causes localized optical breakdown in the switch medium.
4. A laser causes volume ionization along its total path (e.g., along the interelectrode axis of the spark gap).

Let us consider some specifics of the more important mechanisms leading to low delay, low jitter operation.

Laser-Electrode Interaction

The most commonly used method to laser-trigger spark gaps is to focus the laser light onto the surface of one of the electrodes, resulting in the formation of a plasma on the electrode surface or e.g. the emission of electrons at the cathode. The optical development of such an initial breakdown process in a configuration where the cathode was irradiated by a Nd:YAG-laser with a power of several MW is shown in the paper by Dougal, Williams and Guenther [3] (Fig. 4) in these Proceedings. A streamer develops rapidly from the electrode plasma which bridges the gap along the entrant path of the laser and finally causes thermalization and breakdown of the gas. This is the moment at which a rapid rise of current is observed.

The time between laser irradiation and current rise, the delay time, is dependent on a multitude of parameters such as the percentage of self-breakdown voltage, electrode material, fill gas and pressure, laser type and laser power, etc. Fig. 1 shows the

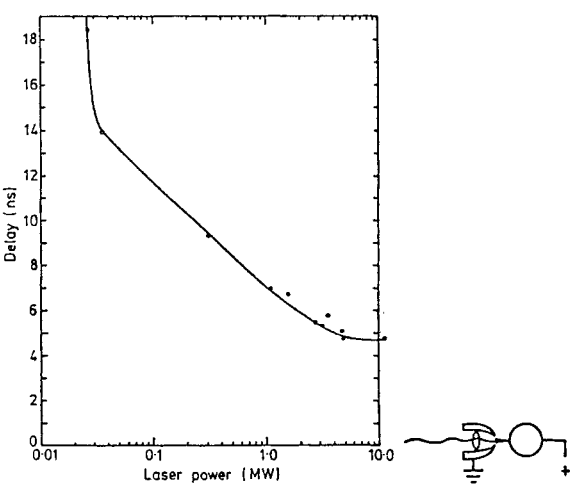

Fig. 1a. Delay vs laser power in 90% Ar-10% N_2, stainless steel anode. Total laser duration 14-15 ns. The pulse width (FWHM) 5.6-6.5 ns. p=2925 Torr, V_{SB}=48kV, V_{CH}=43.2kV [4].

delay versus laser power and, for the same experimental setup, jitter versus laser power. These experimental results obtained by Bettis and Guenther with a ruby laser in 1970 [4] demonstrate the excellent performance (jitter ∿ 100 psec) of laser triggering even at relatively low laser powers (∿ 40 kW).

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14. ABSTRACT
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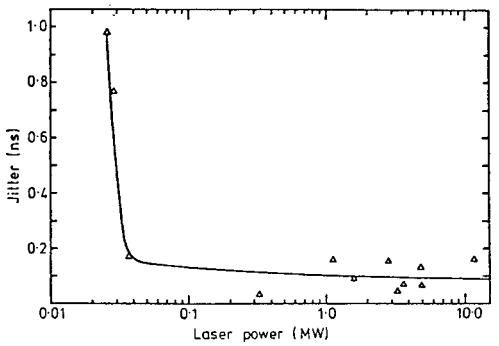

Fig. 1b. Jitter vs laser power in 90% Ar-10% N_2, stainless steel anode. p=2925 Torr, V_{SB}= 48kV, V_{CE}=43.2kV [4].

Subnanosecond jitter was observed employing laser powers of 10 KW by Schildbach and Basting [5] at a reduced voltage V/V_0 close to unity. They obtained nanosecond delay and jitter at power levels as low as 2 kW. There, the corresponding energy of a 2 to 3 ns (FWHM) dye-laser pulse was 5 µJ. Triggering here was always initiated by plasma formation at the cathode.

Spark gap triggering was even obtained at power levels as low as 0.15 kW by Pinnekamp, Himmel, and Bergstedt [6]. Using frequency doubled Nd:YAG laser light, they investigated breakdown conditions in the sub-kW power range. As an initiation process, thermal emission of electrons was assumed. Yet, another model was proposed by Harsch, Salzmann, and Strohwald to explain the trigger effect at low power levels [7]. They performed measurements in the same power range as Pinnekamp et al. and concluded from their data that a two-photon process at the electrode was operative.

All the results discussed so far were obtained with visible, near-UV and near-IR lasers. A considerable amount of investigation has also been performed with CO_2-lasers at wavelengths of ∿ 10 µm. Studies on the breakdown mechanism for CO_2-laser-triggered spark gaps where the laser is focused on an electrode seem to indicate that the ignition process is similar to that at shorter wavelengths. It is assumed that the electrode material is heated, evaporated, and partly ionized. Breakdown results from the development of an electron avalanche initiated in the products of surface evaporation [8]. Microscopic irregularities on the surface support this process [9].

In general, results of measurements with different lasers are not easily compared even though important parameters such as delay and jitter are usually determined in terms of output laser power. However, the important laser parameter seems to be the power density and caustic, a value which is due to different beam quality, the optics employed, and mode structure very difficult to measure.

Laser-Gas Interaction/Spark Discharge

The results of laser triggering which have been discussed so far were obtained with the laser radiation focused onto the electrodes. Another mode of spark triggering is based on generation of an optical breakdown in the gas, which initiates the spark breakdown. Investigations on laser midgap triggering were performed at Texas Tech University [3]. After the laser interaction in the center of the gap, a diffuse plasma is generated, which is stable for only a few tens of nanoseconds. After that time, instabilities occur at the electrodes and channels are formed which grow toward the center and bridge the gap. This trigger mechanism requires higher laser power than those previously discussed and is therefore not recommended.

Laser-Gas Interaction/Volume Discharge

A fundamentally different optically triggering mechanism has been used by Rapaport at Lawrence Livermore National Laboratory [10] and Woodworth, Frost, and Green at Sandia National Laboratories [11]. Instead of generating a point plasma at an electrode or in the gas, a volume ionization was achieved in the dielectric gas by use of an UV-laser. In the later case, a low divergence KrF excimer laser was used to trigger a 0.5 MV, pulse-charged switch in pure SF_6. The KrF beam was focused so that the focal point was between the switch electrodes along the interelectrode axis. With a total laser energy of 0.12 J, visible plasma channels stretching almost the entire length of the gap between the electrode were generated. The dominant electron generation mechanism is obviously a multiphoton process. Four KrF photons are required to ionize SF_6.

The results as delay versus percentage of self-breakdown voltage are shown in Fig. 2. It is important to note that there is only a 0.5 ns difference in delay between 80 percent and 90 percent self-breakdown voltage, affording a low overall jitter in a multigap system where the % SBV or optically dimension and alignment may not be matched. The jitter for events above 70 percent of self-breakdown

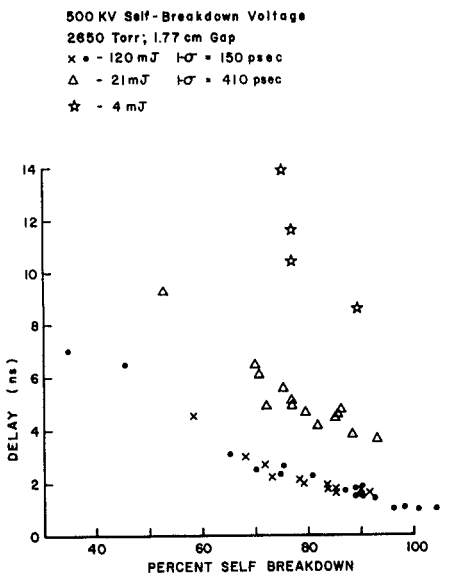

Fig. 2. Switch triggering results using uv laser-induced breakdown of pure SF_6 with a low divergence KrF oscillator-amplifier used as the trigger source [11].

is ± 150 ps. The efficiency of the laser radiation can be enhanced by using a seed gas with low ionization potential [12] (trimethylamine [13], tripropylamine, fluorobenzene, triethylaniline), such that ionization involves at most a two-photon process compared to a four photon process in pure SF_6. In this case, much lower laser powers are required. These investigations were performed with the intention to trigger simultaneously 36 main gas switches, each of which must first hold off a pulsed voltage of ∿ 2.7 MV, then be triggered with a temporal jitter of less than a few nanoseconds.

The potential of laser triggered switching for repetitive multi switch operation was demonstrated in 1970 by Guenther et al [14]. With one laser four separate switches were triggered with subnanosecond synchronization. Guenther and Bettis [15] showed that it is even possible to generate two separate channels simultaneously in one spark gap system. In this experiment the laser beam was split geometrically

between two apertures and then focused on two opposite electrode elements. In experiments performed at Texas Tech University [16] similar results were obtained with the laser light fed through two optical fibers into the spark gap system, a method which allows a simple optical arrangement, eliminating many alignment considerations. Precise time delays may be added by introducing measured lengths of fiber.

Laser-Semiconductor Interaction

Laser triggering is not only used to generate breakdown in gas spark gaps, it has also been demonstrated in solid, liquid, and vacuum gaps [2]. One switch medium destined to become more important for pulsed power applications is the semiconductor. Ionization through carrier generation in the semiconductor is uniformly produced by single-photon photoionization; whereas in gases, volume ionization, even with UV lasers, generally is still a less efficient multiphoton process.

The advantages of optically controlled semiconductor switches compared to gas switches were recently summarized by Nunnally [17]:

- The energy required to produce a carrier pair is the band gap energy instead of the ionization energy.
- The total number of carriers required are produced simultaneously and uniformly between the electrodes.i.e., it follows the laser intensity.
- The spatial and temporal carrier density can be controlled externally during closure and conduction.
- Heat can be removed from the conducting medium in situ.
- Recovery or recombination of carrier pairs depends upon the photoconductive material and heat removal.
- The location of the conduction path can be distributed precisely to provide the minimum inductance.

Delay and jitter is expected to be in the ps regime, the achievable value being light-source limited. In addition, photoconductors are almost arbitrarily scalable.

The advantages of precisely controlled delay and low jitter were demonstrated by Auston [18] at Bell Telephone Laboratories. In his experiment employing mode-locked Nd-YAG lasers silicon devices were switched on and off on time scales of 10 ps. Several interesting experiments on laser-triggered semiconductor switches were performed recently by G. Mourou [19] and C. Lee [20]. Two experiments which demonstrate the advantages of optical semiconductor switching compared to gas spark gap switching will be discussed. The photoconductive switch consisted in both experiments [19] of a piece of high-resistivity semiconductor (usually GaAs or Si) inserted along the central conductor of a coaxial cable. The length of the crystal is typically a few mm.

In the first experiment switching was based only on the photogeneration of carriers in the semiconductor bulk by a picosecond laser pulse. Optical energy requirements are typically tens of microjoules to switch up to 10 kV into a 50 Ω load. The risetime is dictated by the laser pulse characteristics and the electrical circuit, while the maximum obtainable pulse length is dictated by the carrier recombination time, which ranges from ps to μs depending on the specific semiconductor material. A typical 1 kV output pulse is shown in Fig. 3. The observed risetime is 100 ps, and the pulse duration of 2 ns corresponds to the charge line length.

The switching efficiency of ∿ 10 μJ/MW in the experiment discussed can be increased by using avalanche effects in semiconductors. Laser triggering of avalanche transistors was studied at Lawrence Livermore National Laboratory by Thomas and Coleman [21]. By direct optical triggering of one avalanche transistor in a series string of transistors nanosecond-rise kilovolt waveforms were generated, with time jitter being less than 100 ps. In a switch experiment performed by Mourou [19] the avalanche effect in the semiconductor bulk was utilized. The experimental setup is shown in Fig. 4. The GaAs sample was cooled down to 77 K, to reduce thermal breakdown at high electric fields. Switching was initiated by a deeply penetrating, 1.06 μm light pulse. Through the creation of additionally charged carriers in the bulk of the sample, impact ionization was initiated which lead to an avalanche process. Light energies as low as 35 nJ were sufficient to trigger this process, corresponding to an efficiency of 0.5 μJ/MW at 77 K.

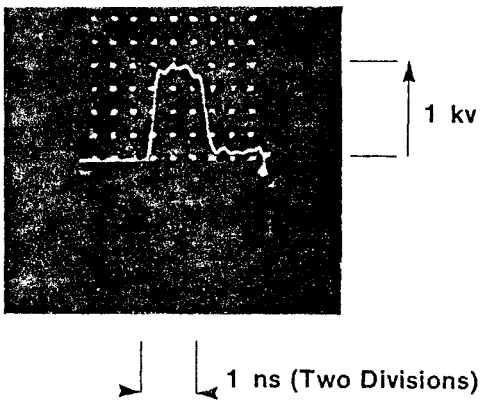

Fig. 3. A trace from a Thomson CSF TSN 660 oscilloscope. A DC bias voltage of 2 kV was used [19].

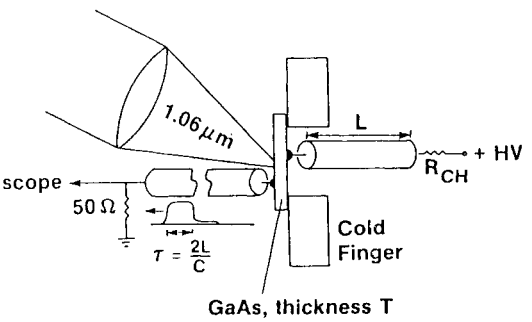

Fig. 4. Schematic of the arrangement. A cable of length L, charged through R_{CH}, is discharged through the cooled GaAs sample, which is triggered by the 1.06 μm laser light. This produces a HV pulse of duration $\tau = 2L/C$ [19].

In this experiment, the GaAs switch replaced the center conductor in a 50 Ω transmission line which also served as a charge line. Figure 5 exhibits the high voltage pulse switched from this device. The photoconductive contribution of the optical signal, triggering the avalanche, can be seen to the left of the pulse. Risetime of the pulse is ∿ 1 ns, with a delay of 1.5 ns and a jitter of 150 ps.

The two examples demonstrate the applicability of semiconductor switches in pulse power systems where high timing accuracy is required. The primary limitation of these switches is the burden placed on the laser and contact resistance, thermal heat sinking and low inductance connection. Critical research in this field is just beginning. Many semiconductor systems are increasing in the application to many pulse power systems.

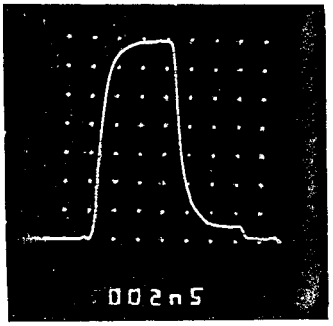

Fig. 5. A typical HV pulse switched through the GaAs spark gap. The photoconductive contribution is the small wiggle ∿ 500 ps before the foot of the main pulse [19].

LASER CONTROLLED DIFFUSE DISCHARGES

Diffuse discharges seem to offer a variety of advantages with respect to their applications in switching. One is that large area discharges offer an ease in impedance matching of a switch to a PFN, and through the low current density one will realize less erosion affording longer lifetime. On the other hand, large area diffuse discharges are unstable, and operation is generally possible for only short periods, depending, in the main, on the discharge parameters. Another aspect to be considered is that a diffuse discharge is a cold discharge, not in Local Thermodynamic Equilibrium, allowing one to influence individual transitions illuminating with a resonant frequency, thus controlling the subsequent density of states important in the generation or depletion of electrons.

As mentioned in the section on laser triggering, the increasing diversity, infact selectivity, of laser wavelengths has opened the possibilities of using other mechanisms for discharge control. For example, there are several processes that allow one to change the electrical properties along the total length of a path between the electrodes of a spark gap rather than just initiating the breakdown process in a limited volume element. Here the laser is acting on the gas in a spark gap clearly before LTE is reached; and, as such, the processes may be the same as employed in diffuse discharge switches. It is desirable to have the diffuse discharge remain relatively cold, so that the above mentioned possibility of influencing specific transitions is maintained, allowing one to control the closing and opening phase of discharge, i.e., to change the conductivity in either direction, as a closing or as an opening switch as first proposed by Guenther [12]. Normal or enhanced recovery of fast reprated closing switches is an opening process and therefore will be discussed herein in that context.

The existence of optogalvanic effects has been known for a long time. Townsend [22] showed in 1902 that UV light emitted by a spark can initiate conductivity in gases when an applied voltage is present which is otherwise too low to maintain a discharge. Starting in the late twenties of this century, several very interesting papers appeared, showing that light at the wavelength corresponding to an optical transition will change the electric properties of the discharge. In an experiment by Pennings [23] for example, the light emitted by one Ne discharge was used to illuminate another Ne discharge.

It wasn't until the advent of lasers, particularly tunable lasers, that a vertible flood of papers on optogalvanic spectroscopy was seen (for an overview see [24]), principally initiated by those of Green et al. [25] and Bridges [26]. In optogalvanic spectroscopy, a given laser wavelength can produce a specific response in a discharge; whereas for switching applications, the magnitude and direction of the response is the main objective. We will present an overview of these processes that have been considered as having potential as control mechanisms for switching and will also mention some recent results of research groups working in this area, either related to investigations of basic processes or to their application in switching devices or other related areas.

Before discussing the interaction of light with specific energy states, let us recall that the interaction of light with free electrons via Inverse Bremsstrahlung is considered to be the dominant process for IR optical breakdown in gases or the interaction of the laser with the propagating streamer in IR laser triggering. However, the total energy required makes it generally unsuitable for large volume discharges.

The interaction of light with specific energy states can be used to increase or to decrease the conductivity by controlling either the electron generation or depletion. Optically increased conductivity can be accomplished by photoionization or excitation with collisional assistance or by photodetachment, which may be considered as an electron generation process if negative ions are present or as an elimination of electron losses via attachment. Optically decreased conductivity can be accomplished by optical quenching of excited states or by optically enhanced attachment.

Let us discuss the following optically controlled processes which can be used to increase the conductivity:

(1) Single photon ionization does not in fact require any wavelength tuning above some energy threshold. Most TEA lasers employing UV preionization with spark radiation sources use this process [27]. The efficiency of UV ionization can be drastically increased using gas additives with low lying ionization levels [28]. Spark UV sources can also be used to operate a discharge below the glow voltage, sustained entirely by photoionization [29].

Considering that commonly available lasers produce photons up to energies of approximately 7 eV efficiently, only a few gases, like alkali vapors, are suitable for direct photoionization using lasers [30] but gases can be seeded with easily ionized impurities.

(2) Resonant two-step photoionization (Fig. 6a) appears to be a more efficient way to generate electron-ion pairs. Consider that UV excimer lasers have produced significant electron densities in several organic molecules [31]. For example, in trimethylamine, Lee and Bischel [13] produced an electron density of $10^{15}/cm^3$ with a 10 ns, KrF laser at 248 nm over a 2 cm^2 cross section area. As previously noted, the UV laser triggering of gas filled gaps with organic additives at Sandia National Laboratories uses

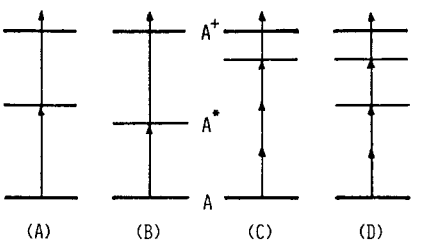

Fig. 6. Multiphoton ionization proceses:
(a) Resonant two-photon process (one wave-length)
(b) Resonant two-photon process (two wave-length)
(c) Resonant enhanced four-photon process,
(d) Doubly enhanced four-photon process.

this process [11]. Also long plasma channels exceeding 1 m length have been generated with different organic additives in a buffer gas [32].

A diatomic molecule suggested for efficient resonant two step photoionization with narrow bandwidth lasers is NO [33]. John Moseley et al. at the University of Oregon [34] proposed to use the radiation from a KrF laser, Anti-Strokes Raman shifted in H_2, to operate in the spectral region of X→A transitions. The un-converted fraction of the KrF laser can then be used to provide the second photon to produce ionization from the A-state.

Resonant two step photoionization at different wavelengths in Cesium (Fig. 6b) is now being used at Sandia to provide large volume ionization in an ionization front accellerator [35].

(3) Multiphoton ionization will in general involve one or more nonresonant steps and the subsequent ionization rate will depend strongly on the intensity of the laser beam. Thus, it is not an efficient mechanism to produce large volume ionization. However, it may be a suitable mechanism for laser triggering acting either on the electrode or in the gas. Williams [36] used four-photon ionization in Xe involving one resonant step (Fig. 6c). With a pulse energy of approximately 300 μJ he could produce more than 10^{10} electron-ion pairs in a volume of approximately 10^{-5} cm^3.

Some molecules allow a double enhancement of multiphoton ionization. In NO a transition from the ground state to the (A)-state requires twice the energy of the transition from the (A)-state to a higher lying Rydberg state, and this same energy is sufficient to ionize NO in a subsequent step. This is a doubly resonant enhanced four-photon transition with only one nonresonant step (s. Fig. 6d), requiring a wavelength of approximately 450 nm [37].

(4) Photoexcitation and subsequent collisional ionization has already been used by Green and co-workers in laser enhanced ionization spectroscopy [25]. Photoexcitation, in most cases starting from an excited state with subsequent collisional ionization is the key process in optogalvanic spectroscopy.

Another mechanism, laser resonance pumping [37] has been demonstrated in several alkali vapors. In this case, if the absorption of a resonant transition is saturated, then the density of the resonance state is nearly the same as that of the ground state. Here the probability for an electron to collide with an excited atom is very high; and through super elastic collisions, the electrons can gain enough energy to ionize the gas. Ionization by laser resonance pumping is now being investigated at Sandia National Laboratories to produce large volume ionization for a high purity lithium ion source for one of their particle beam fusion accelerators [38].

(5) Photoionization from collisionally excited states can result in a large effect in systems with high densities of excited species or in systems where the rate into such an intermediate state is large. For example, in mercury high densities of metastables in the $6\ ^3P_0$ state can be produced.

(6) Photodetachment is one way to overcome attachment in a well defined switch period or in specific areas of a discharge. As such, photodetachment may be an important mechanism in UV laser triggering of SF_6 filled gaps [39].

In the case of diffuse discharge opening switches, attachers must be used to achieve fast opening [40]. However, during the conduction phase photodetachment may be used to eliminate electron losses via attachment. In experiments at Texas Tech University [41] in O_2-discharges and flowing afterglows, it was shown that strong optogalvanic signals can arise from photodetachment of O^-. For an energy flux of 35 mJ/cm^2, 50% of the O^- ions could be photodetached. An advantage of photodetachment is that it is a nonresonant process and therefore it can easily be combined with other optical control mechanisms [42].

(7) Quenching of metastable atoms or molecules (Fig. 7) may also be a suitable mechanism to control the conductance of a discharge particularly if the electron generation, dominated by two-step ionization via metastables, can be controlled. In addition,

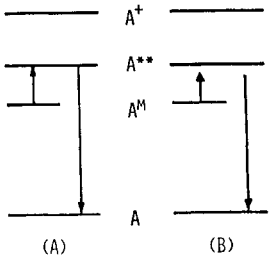

Fig. 7. Quenching of metastables: (a) Resonant and (b) Anti-Stokes Raman process.

the recovery of a gas, following a discharge pulse, can be affected if long living excited species dominate the recovery phase.

Quenching as used here describes the dissipation of energy deposited in metastables in the discharge by exciting a higher lying level which is optically connected to the ground state (Fig. 7). If this resonance radiation can escape the discharge vessel, the energy will not even contribute to heating of the ambient gas.

Lawler at the University of Wisconsin is studying the role of metastables in rare gas discharges and the effects caused by changing the metastable density [43]. A paper at this Conference [44] describes the specific role of metastables in the cathode fall region. It is shown that metastable atom bombardment is an important mechanism controlling electron emission from the surface of cold cathodes. Thus, a decrease of the metastable density in front of the cathode will decrease the electron emission rate. This effect is amplified by the fact that each electron, emitted from the cathode, gains enough energy in the cathode fall to produce several additional electrons through ionization.

Gundersen and his group at the University of Southern California are looking at the role of molecular metastable species in the operation of hydrogen thyratrons and other applications [45], including the possibility of using Anti Stokes Raman Scattering as a quenching mechanism (Fig. 7b). Although this process has the disadvantage of being a non resonant process it has the advantage that the same frequency can be used when quenching different rotational states of a metastable molecule. An important aspect of their work is a determination of the dependence of the metastable lifetime on the intensity and frequency of the incident optical radiation.

The last group of processes to be discussed relates to optically enhanced attachment [46]. Certain attachers have an increased attachment cross section in their rotational and/or vibrational excited states. The mechanism can be understood by considering the potential energy curves of a diatomic molecular attacher and its negative ion. In Fig. 8, a general type of dissociative electron attachment process is illustrated. The potential energy curve of a neutral diatomic molecule AB is crossed at an energy E_v^* above the ground state by a repulsive branch of the negative ion AB^-. The probability of electron attachment and succeeding dissociation depends principally on the energetic state of the vibrationally excited molecule relative to the curve crossing. For the example shown, the attachment cross section

increases with vibrational excitation up to v = 4. On the other hand, the electron energy necessary to form the negative ion AB^- shifts to small values if the molecule AB is excited into a vibrational state closer to the curve crossing.

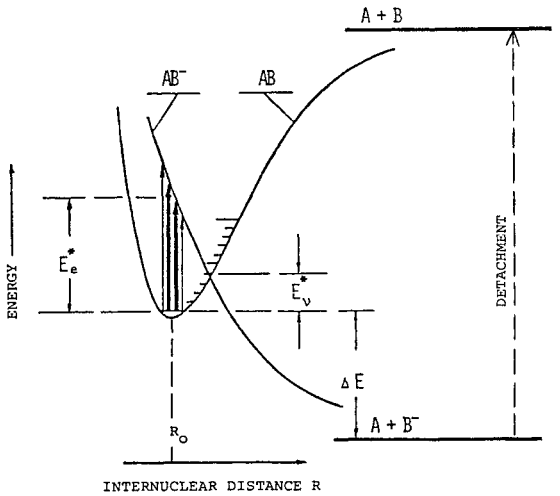

Fig. 8. Resonance associative electron attachment.

As yet, there are no known measurements of attachment cross sections for individual vibrational states. However, Bardsley et al. [47] have deduced the cross section for the vibrational states (v = 0 - 3) of HCl (see Fig. 6 in the paper by Schoenbach and Kristiansen [49] in these Proceedings) from cross section measurements at different gas temperatures by Allan and Wong [48]. These data show that the attachment rate can drastically be increased using vibrational excitation, but this advantage disappears in HCl if the electron energy is larger 0.5 eV.

There are many ways to optically populate vibrational states. The first experiment performed using laser excitation to increase the attachment rate was done in SF_6 by Chen and Chantry [50]. Figure 9 shows the cross section for dissociative electron attachment in producing SF_5^-; (e) the curve without laser at 390°K, (d) with a CW CO_2 laser (8W over 0.3 mm^2), and (f) the laser produced change in the cross section. That this experiment was S-isotope specific, as seen from the laser wavelength dependence, indicates that the laser does not just result in a general gas heating. Recently, similar experiments have been performed in France by Barbe, Astruc, Lagreze, and Schermann using the valence electrons of Rydberg Ar-atoms instead of free electrons [51].

Another possibility for producing highly excited vibrational states is to employ transitions from electronically excited states, either radiative, or through collisions. Such a process has recently been used by Beterov and Fatayev [52] to show that vibrational excitation of I_2 can increase the cross section for dissociative attachment. Figure 10 depicts the excitation mechanism. The radiation from a frequency doubled Nd:YAG (λ = 532 nm) was used to excite the (B)-state. Intense stokes flourescence indicated a subsequent transition into highly vibrational excited states of the electronic ground state. Vibrational relaxation had to provide the population of the optimum vibrational states resulting in an increase of the attachment rate by three or four orders of magnitude.

It is appropriate to finish with some remarks concerning optically controlled discharge modeling. Assume a given device, and one wants to employ optical control processes to improve its performance, at first glance, one immediately notes a large number of transitions that will probably influence the discharge

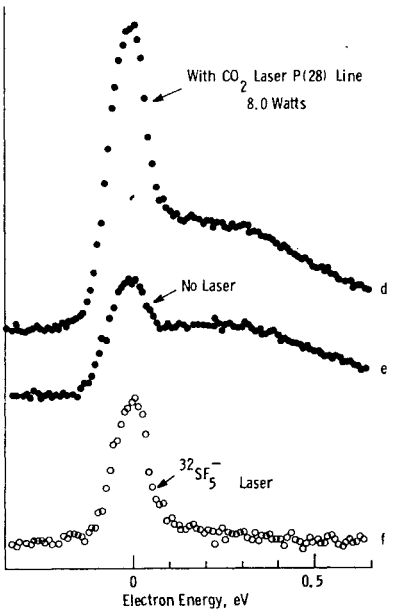

Fig. 9. An example of data showing photo-enhancement of the cross section for the production of SF_5^- from SF_5 (From Chen and Chantry [20]).

to some degree in the direction you desire. To decide which transitions are the most effictive, you must know the dynamics of the excited states, ions, and

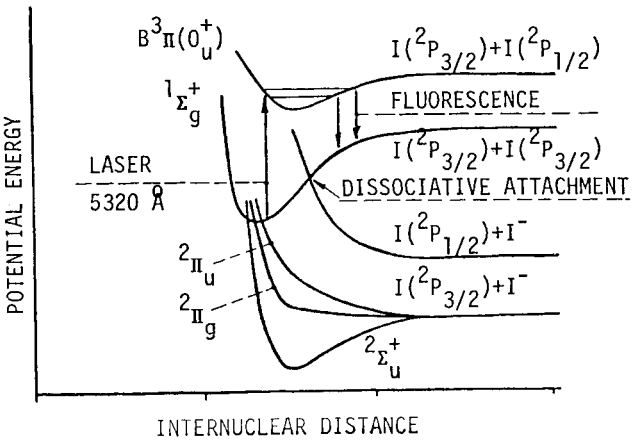

Fig. 10. Some potential curves for I_2 and I_2^- and the scheme of excitation of vibrational levels (From Beterov and Fatayev [52]).

electrons involved in the gas discharge. In general, it is not difficult to design a computer code that allows such calculations; but you have to feed it, primarily, with the rate constants of all the processes that are important in determining the ultimate behavior of the discharge. Most of the rate constants are at least E/N dependent, and the applied field may be changing drastically in time. So one goes to those sources who provide us with the basic data we need.

Additionally, the field strength is strongly influenced by the circuit parameters. In this situation, the efficient use of the available photons requires a very basic understanding of all the processes in the gas discharge as well as an understanding of the interaction of discharge and the circuit. Unfortunately, in a different gas the discharge may be determined by a completely different set of processes, and one must, of necessity start all over again. So it is not surprising that every group

working on specific optogalvanic effects in certain gas mixtures does its own modeling.

But an incomplete or even worse an inapplicable model is not as good as an appropriate measurement. What we need are measurements on the requisite excited states, which are enhancing our ability to model with confidence difficult circuit features such as the time dependent behavior of gas discharge switches in real circuits.

In conclusion we would like to thank many of the cited researchers for providing us with their recent and frequently unpublished results, in most cases with much more detail than we could present here.

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