CO_2-TEA PULSE CLIPPING USING PULSED HIGH VOLTAGE PRE-IONIZATION FOR HIGH SPATIAL RESOLUTION I.R. LIDAR SYSTEMS

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ABSTRACT

An extra-cavity CO_2-TEA laser pulse clipper for high spatial resolution atmospheric monitoring is presented. The clipper uses pulsed high voltage-to facilitate the breakdown of the gas within the clipper cell. Complete extinction of the nitrogen tail, that degrades the range resolution of LIDARS, is obtained at pressures from 375 up to 1500 Torr for nitrogen and argon gases whereas an attenuation coefficient of almost 10^2 is achieved for helium. Excellent energy stability and pulse width repeatability were achieved using high voltage pre-ionized gas technique.

1. INTRODUCTION

The TEA transversely excited atmospheric CO_2 laser pulse temporal profile typically has a tall, sharp spike followed by a long, drawn out nitrogen tail. Although the amplitude of the nitrogen tail is not nearly as high as the initial spike, the tail is drawn out over a time interval of 2–5 μs and holds up to two-thirds of the total energy of the pulse. The nitrogen tail occurs due to the long lifetime of the nitrogen molecule vibrational energy level used to excite the CO_2 molecules and initiate lasing. A sufficient number of nitrogen molecules remain excited after the initial spike to continue the lasing process at a lower power level for the duration of the tail. If there is some low level of near-field scatter into the receiver, this effect can be quite significant, as the aerosol backscatter return is of the order of 10^{-4} of the transmitted power within this wavelength interval. In this case, the unclipped near-field scattered signal can interfere with the weak signal backscattered from the atmospheric aerosols. This type of pulse limits the range resolution of LIDARS to some hundreds of meters unless pulse-deconvolution techniques [1] are adopted. Short laser pulses can also be obtained by various techniques such as mode locking, free induction decay, pulse slicing with electro-optic switched [2-5]. However, output pulses from these require further amplification for any useful application due to their very low energy content. Moreover, laser self-induced gas breakdown clippers are unpredictable due to the large jitter characterizing their operations. They also tend to generate clipped pulses of unstable energies and pulse widths. The use in this work of a HV pulse to pre-ionize the sealed clipper gas prior to the arrival of the laser pulse achieved excellent energy stability and pulse width repeatability of the clipped pulse. The clipper hence achieves high range-resolved remote sensing of atmospheric constituents.

2. RESULTS AND DISCUSSION

The laser beam is usually focused inside the sealed clipper to high field intensities to create self-induced plasma which acts as a pulse clipper. Both higher breakdown levels and long-term stability operations of the clipper dictated the choice of helium, argon, and nitrogen as filling gases [6-8]. The sketch of the CO_2-TEA laser pulse clipper is shown in figure 1. The HeNe laser is used for alignment purposes.

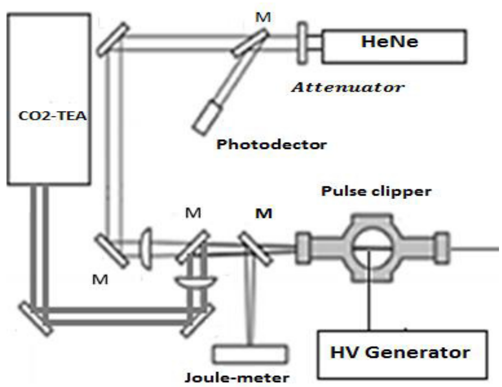

Fig. 1 Sketch of the laser-induced pulse clipper.

The breakdown of the filling gas is hence provided by two separate channels. The first channel is purely electrical and provides a high voltage pulse whose amplitude is just below the gas breakdown threshold but is sufficient to facilitate the plasma initiation by providing starting electrons for the avalanche ionization process for gas breakdown. The second channel is optical provided by the focused CO_2-TEA laser pulse, whose field intensity is far superior to reach or even exceed the threshold of the gas breakdown in the clipper. This electrical-optical sequenced mechanism also achieves fast triggering of the plasma with minimal jitter. Laser-induced clipping in helium and nitrogen is shown in Fig. (2, 3) at the 9P(20) and for argon Fig. 4 at the 10P(20) laser lines. Attenuation of the clipped portion of the laser pulse within 500 ns of the breakdown is approximately 10^2. Average clipping efficiency for helium at pressures of 600–900 Torr is approximately 75%. The latter is far superior than that reported by other authors [2] for a range of pressures extending from 200 to 300 Torr. Complete extinction of the nitrogen tail is obtained at pressures extending from 375 up to 1500 Torr for the nitrogen and argon gases. Attenuation of the clipped portion of the laser pulse is approximately 10^5, which is three orders of magnitude higher than that of helium. No pulse recovery occurs after clipping takes place; nevertheless, the nitrogen and argon plasma clipping drains out almost 40% and 50% of the laser energy, respectively. The evolution the pulse width versus cell pressure for three gases is illustrated in Fig. 5. The pulse width decreases gradually as the pressure of helium and nitrogen tends to 300 Torr and then decreases rapidly between 300–600 Torr to reach a nearly asymptotic value at pressures higher than 700 Torr. As for argon, the pulse decreases very sharply from a nitrogen-tailed pulse to a clipped pulse at pressures as low as 150 Torr. Figure 6 shows the LIDAR return signals where the solid-line curve represents the clipped pulse characterized both by the normal exponential decay of the single gain-switched spike and total absence of the hump, which was initially associated with the nitrogen tail of the TEA–CO_2 pulse. The dotted curve represents the return of the raw pulse.

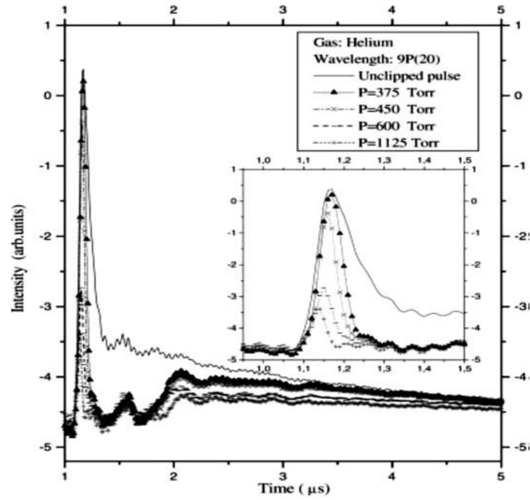

Fig. 2: Temporal profiles of clipped laser pulse versus helium cell pressure.

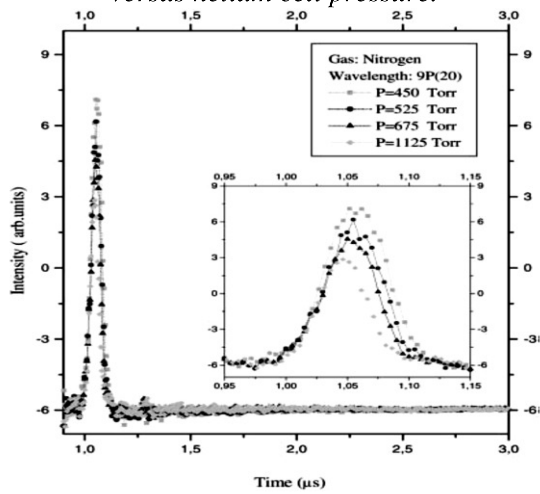

Fig. 3: Temporal evolution of the clipped laser pulses in presence of nitrogen at the various pressures.

Figure 7 shows the threshold breakdown intensities versus the 75–1500 Torr pressure range of helium, argon, and nitrogen. Gas breakdown intensity for the 10(P20) line have been plotted on a $\log(I_{th})$ versus log(P*)* scale and fitted to a straight line with 1%–8% standard deviation of the fits. For helium and argon, the threshold intensities extend from 3×10^{11} Wcm^{-2} –5×10^{12} Wcm^{-2} and from $2\times10^{11}Wcm^{-2}$–$2\times10^{12}Wcm^{-2}$, respectively. The plot shows no evidence for the plateau that illustrates the multiphoton ionization (MPI) processes in gases [3] but does confirms the predominance of the collision ionization process due to the IR emission band of TEA–CO_2 lasers where the laser-induced breakdown is expected to be driven by an avalanche ionization mechanism [4]. For nitrogen, the threshold breakdown intensities extend from 3×10^{13}Wcm^{-2}–2×10^{14} Wcm^{-2} which is rather higher than that of helium and argon due to the additional vibrational energy losses inherent to the nitrogen molecule.

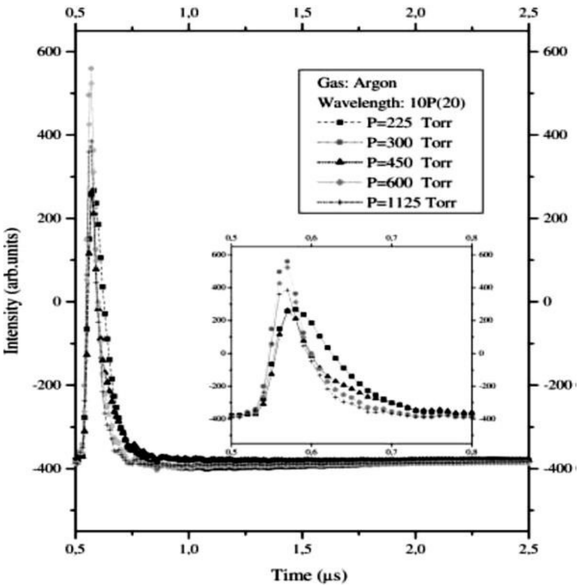

Fig. 4: Temporal profiles of the clipped laser pulse in the presence of argon as a function of pressure.

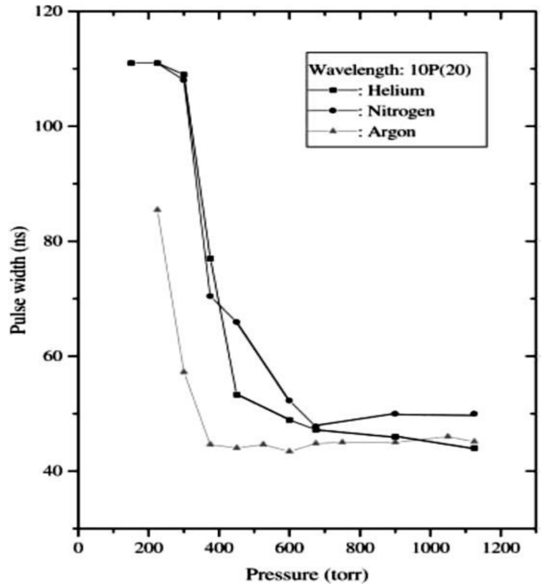

Fig.5: Evolution in time of the clipped pulse width as a function of pressure for helium, nitrogen and argon

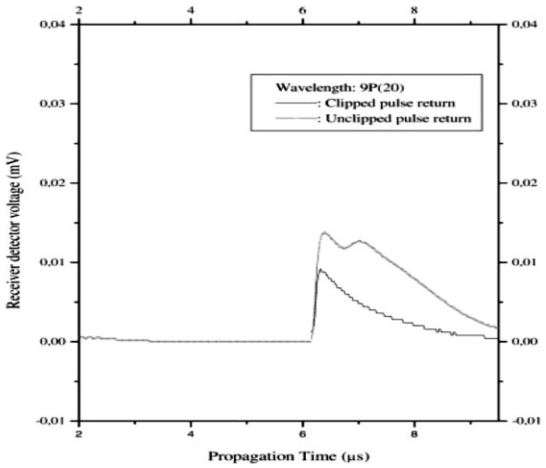

Fig. 6: Typical round trip return of the TEA–CO_2 LIDAR.

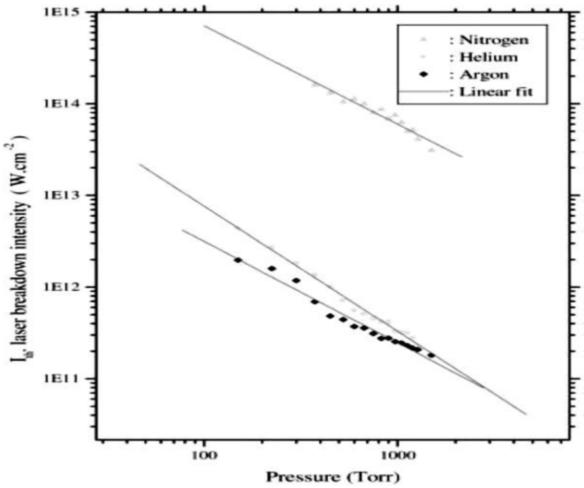

Fig.7: Threshold breakdown intensities for nitrogen, helium and argon versus cell pressure.

Laser pulse energy and stability were studied and it was found that the mean pulse energy was 490 mJ; the standard deviation in energy was 9 mJ as shown in Fig. 8.

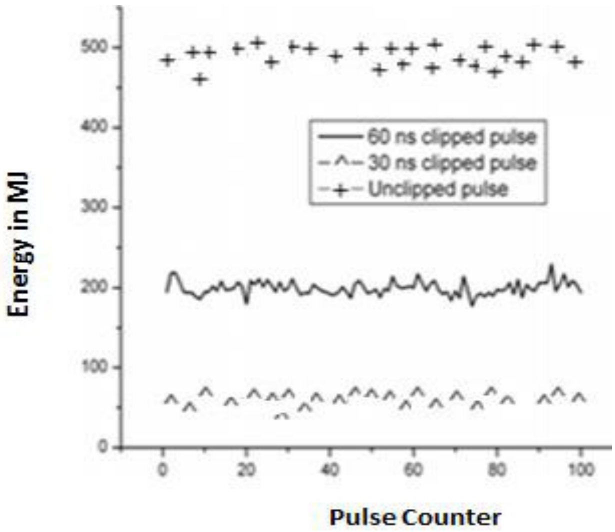

Fig.8: *Pulse stability over 100 consecutive pulses for 30 and 60 ns clipped pulses and the unclipped pulse.*

3. CONCLUSION

We present a high stability and energy-efficient laser-induced plasma clipper to clip the nitrogen tail of CO_2-TE based LIDAR. Optimum pressures for helium, argon, and nitrogen, that provide the best stability of the transmitted energy and complete extinction of the nitrogen tail, are located within the 450–600 Torr interval. Excellent range resolutions can now be achieved with TEA–CO_2 laser-based LIDAR systems.

References

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