ONE-NOZZLE TWO-BEAM LASER-DETONATION SYSTEM

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ABSTRACT

One-nozzle two-beam laser detonation system, which is capable to produce two hyperthermal beams from single nozzle, was developed for sub-low Earth orbit (LEO) material tests. Unlike conventional laser detonation system with mixed target gas, translational energies of two beams could be tuned independently. This is important feature for evaluating survivability of the materials in sub-LEO environment which is suffered by the simultaneous N_2 collisions under AO exposure. Pulsed supersonic valve (PSV) with displacement enlargement mechanism was specially designed for this purpose. Conventional single PSV system is easily replaced to this dual-PSV system such that low-cost sub-LEO simulation could be achieved.

1. INTRODUCTION

According to the development of superlow altitude test satellite (SLATS or "Tsubame (swallow)", launched on December 23, 2017), atomic oxygen (AO)-induced material degradation in the altitude at around 200 km has been focused. The neutral gas environment in the altitude of 200 km is different from that of 450 km, i.e., as high as 50% of fraction is N_2 balance AO. Also N_2 and AO densities are much higher than those in 450 km. A ground-based study indicated that the simultaneous bombardment of energetic molecules promoted the etching yield of polyimide [1, 2]. For such studies, hyperthermal AO and N_2 (or Ar) beams need to be formed. A crossed laser-detonation system has been developed for this purpose [2]. However, this system requires cost and space twice as large as conventional laser-detonation system as well as high technical skills even in low exposure throughput.

In order to solve these problems, new hyperthermal AO beam system which equips two pulsed valves was newly developed to form two hyperthermal beams from the same nozzle.

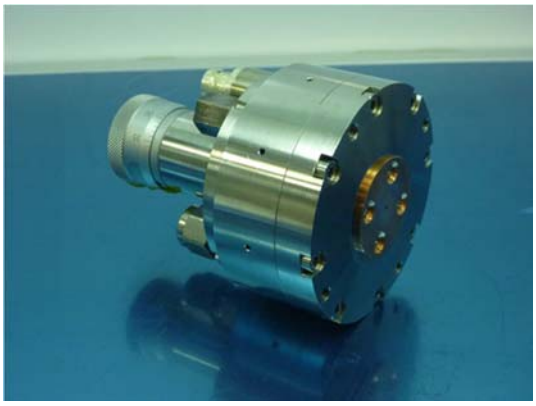

Figure 1 Pulsed supersonic valve using PZT disk transducer

2. PULSED SUPERSONIC VALVE

Figure 1 shows the PSV using a PZT disk transducer which has been used for laser detonation source in Kobe University. This PSV was supplied from Professor Minton at Montana State University. This PSV has an excellent performance to produce hyperthermal AO beam for LEO material tests, and has been used for more than 10 years at Kobe University. The diameter of this PSV is 70 mm and this is due to that of disk transducer used (50 mm in diameter). In order to produce two beams form one nozzle, two PSVs need to be attached to the nozzle. A large diameter of PSV leads to long flow channels between the valve sheet and the nozzle throat. This should be avoided to form a hyperthermal beam pulses of target gas. It is, therefore, thin PSV needs to be developed for dual-PSV system.

Figure 2 shows the PSV newly developed in this study. It is rectangle shape and the dimensions of this PSV is approximately 100×40×150 mm (including micrometer). It equips low-voltage PZTs with displacement enlargement mechanism which is commercially available [3]. The operating voltage of the PZT is 150V which lower than that of disk transducer (e.g., 1 kV). The low operation voltage prevents the unexpected discharge. These mechanisms are covered by the stainless steel body.

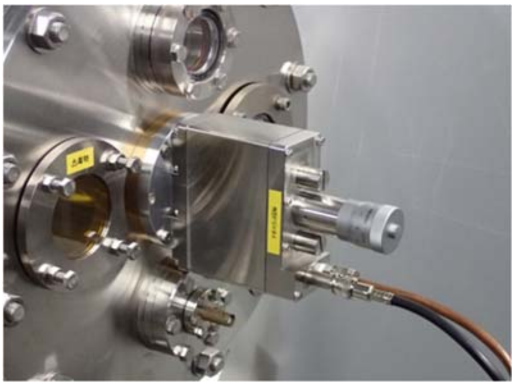

Figure 2 Rectangular shape pulsed supersonic valve developed in this study (upper panel) and single-PSV configuration (lower panel)

A target gas is ejected through 1 mm hole and sealing is made by a Viton O-ring. The poppet clearance is adjustable by the micrometer. The poppet system with a Viton O-ring and Au reflector was specially designed for laser-detonation applications, which requires the focusing 7J laser pulse near the O-ring.

A pressure profile of ejected gas from the nozzle was measured in atmospheric condition. It is clearly indicated that the PSV is able to operate less than 100 microseconds (rise-up time, Figure 3). It should be

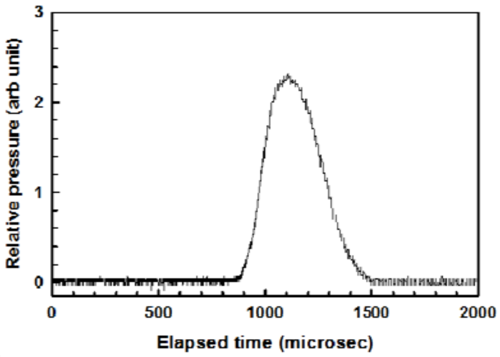

Figure 3 Pressure profile of new PSV measured in atmospheric condition

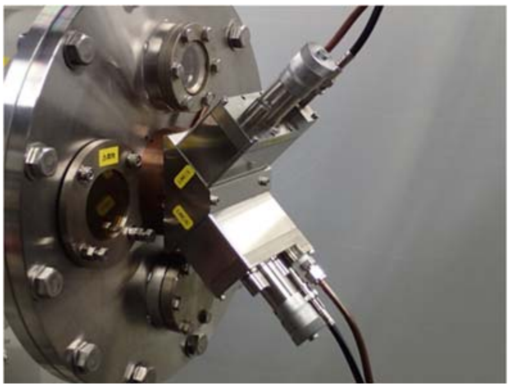

Figure 4 Dual-PSV configuration

mentioned that even faster operation is possible with a high-power PSV driver. It was also confirmed the specifications below;

- Max. pressure of supply gas: > 0.8 MPa
- Max. repetition rate: > 50 Hz
- Poppet life: > 400k shot (with CO_2 laser irradiation)

For dual-PSV system, two PSVs need to be attached to the nozzle throat. Figure 4 shows the appearance of the dual-PSV system. The attached angle of PSV is 45° with respect to the beam axis. The distance of valve sheet and nozzle throat is minimized for each channel.

3. SYSTEM CONFIGUTRATION

Figure 5 shows the block diagram of the dual-PSV system. In order to avoid the interference of pulse timing, two system clocks (TTL signal) with phase difference of 180° are used for each PSV. One of the TTL signals are decimated for tuning the flux ratio of the gases. TTL signals are converted to designated shape of the PSV driving signals by the function generators and the driving signals are amplified by the PSV drivers. Laser timings

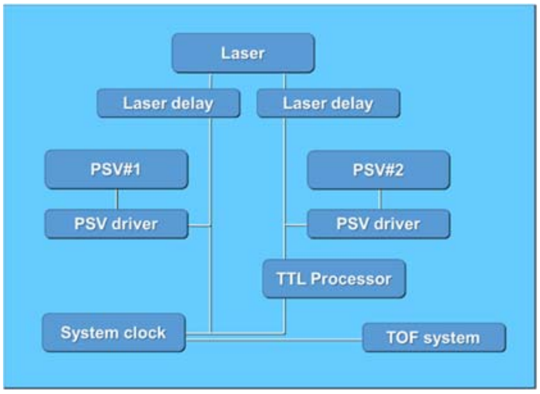

Figure 5 Block diagram of dual-PSV configuration

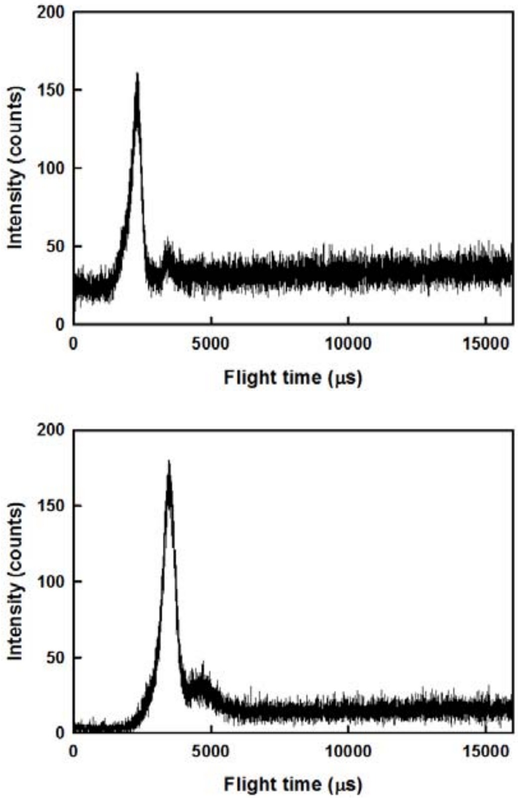

Figure 6 Time-of-flight spectra of thermal O2 and Ar beams detected by QMS in dual-PSV configuration; upper panel: m/z=32 and lower panel: m/z=40

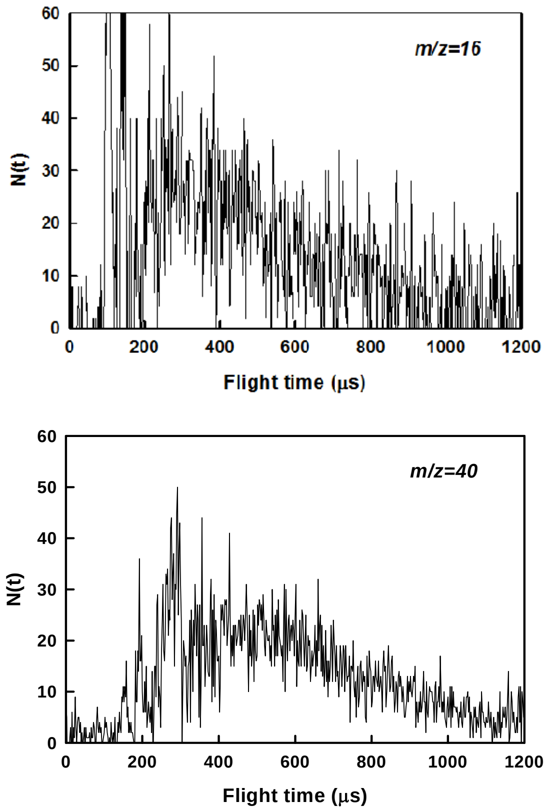

Figure 7 Time-of-flight spectra of hyperthermal thermal AO and Ar beams detected by QMS in dual-PSV configuration; upper panel: m/z=16 and lower panel: m/z=40

for each gas was adjusted by the digital delay generators individually. Both delayed signals are connected to the CO_2 laser. The maximum repetition rate of PSV is over 50 Hz, however, the system repetition rate was restricted by that of CO_2 laser (5 Hz). Conversion from single-PSV to dual-PSV (and v.v.) is quite easy since the same conical nozzle is used for both system. It could be completed within a few minutes.

4. TIME-OF-FLIGHT SPECTRA

Time-of-flight (TOF) spectra of “thermal” molecular beam pulses formed with the dual-PSV system were measured. Figure 6 showed TOF spectra of thermal O_2 and Ar beam pulses ejected from the each PSV. The thermal beam pulses of O_2 and Ar were clearly detected by the quadrupole mass spectrometer (QMS) with scintillation detector. It was also obvious that the velocity distributions are consistent with the Maxwell-Boltzmann distribution, which indicated that the dual-PSV system works as expected.

Figure 7 shows the TOF spectrum of hyperthermal O-atom beam with CO_2 laser firing. Average translational energy of 4.7 eV was obtained. The flux of O-atom reached approximately 5E+14 atoms/cm^2/pulse (Kapton-equivalent flux). From these experimental data, the dual-PSV system is confirmed to be operational as a sub-LEO neutral environment simulator, even though hyperthermal N_2 beam pulse still could not be formed.

5. SPILLOVER EFFECT ON SEE COMUNITY

The former dual-beamline hyperthermal beam system (Figure 8) was replaced to the dual-PSV system (Figure 9). Surplus components of the crossed laser-detonation system were diverted for another conventional laser-detonation AO system at Kobe University available to low-cost AO exposure services worldwide regardless its scientific purpose. [4]

CONCLUSIONS

One-nozzle two-beam laser detonation system was developed at Kobe University with newly developed thin-shaped PSV with a displacement enlargement

Figure 8 Photographs of the dual-beamline configuration (upper panel) and dual-PSV configuration (lower panel) of the sub-LEO neutral gas simulation facility at Kobe University

mechanism. It provides hyperthermal AO/O2 and Ar beam pulses on the same beam axis. This system was successfully applied to study the effect of undecomposed O2 molecules on ground-based AO-induced material degradation tests [5].

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