RESULTS OF A UV TEPS/RAMAN SYSTEM FOR STANDOFF DETECTION OF ENERGETIC MATERIALS

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ABSTRACT

A fully integrated UV Townsend Effect Plasma Spectroscopy (TEPS)-Raman system has been constructed for use of standoff detection of energetic materials. A single 266nm Q-Switched Nd:YAG Laser was used for Raman excitation and TEPS plasma ignition. A nearly simultaneous 10.6um CO_2 laser is employed for the signal enhancement in the TEPS measurements. Chemometric techniques are presented for analysis and differentiation between benign and energetic samples. Data Fusion techniques are then employed to improve the measurement statistics.

1. INTRODUCTION

Laser spectroscopy is a leading candidate for solving the standoff Explosive Detection (ED) detection problem. While there are several techniques, two of the most promising approached are Laser Induced Breakdown Spectroscopy (LIBS) (DeLucia et al 2003, Miziolek et al., 2006, Lopez-Moreno et al., 2006) and Raman (Sharma et al., 2003). In fact Leading Department of Defense scientists and administrators have stated 'LIBS plus Raman working in the UV holds the most promise' for solving the standoff Explosive Detection Problem (JIEDDO presentation at SPIE Defense Conf. 2007). Alakai's approach is to combine these two orthogonal techniques, with a new proprietary LIBS enhancement technique called Townsend Effect Plasma Spectroscopy (TEPS), into a single system for ED.

The benefit of this TEPS implementation is that the resulting signal strength is enhanced on the order of 25 – 300 times (Killinger et al., 2007) compared to a standard single pulse LIBS event. This tremendous signal enhancement provides sufficient design margin thereby allowing the laser wavelengths to be shifted to the UV for λ^{-4} Raman Enhancement and Eye Safety implications.

2. EXPERIMENTAL DESCRIPTION

The following paragraphs provide a description of the TREDS-2 hardware along with the design and performance decisions that impacted its performance

2.1 Hardware Description

A model of the second generation TEPS-Raman Explosive Detection System (TREDS-2) system is shown in figure 1 with a photo shown in figure 2. The TREDS-2 system consist of a Q-switched 266 nm 4x Nd:YAG laser (Frequency Quadrupled Quantel Brilliant B) focused onto the target with a custom designed beam expander & focusing optics. A high-power pulsed CO_2 Transverse Electrode Atmospheric (TEA) laser (Lumonics Model 960) was focused through a custom beam delivery system onto the same target to provide the TEPS enhancement phenomena. The plasma produced on the target was collected using a 14 in diameter telescope (Meade LX200-14) which was fiber coupled to an Andor Spectrometer (Shamrock SR303) & ICCD Camera (DH740-18F). The timing of the lasers and spectrometers was controlled with custom electronics. For TEPS the nominal Nd:YAG-CO_2 delay was 0.5us and the Spectrometer Gate delay was ~6µs with a 6µs gate width. For Raman, the nominal gate width is 1µs with no delay. All this equipment was mounted in an Air Conditioned Trailer which was powered by an 8KW Generator.

2.2 Eye Safety

One of the key design parameters of the TREDS-2 system was eye safety. Since this system would eventually need to be fielded, design decisions needed to insure that the overall system would present the lowest risk possible to operators and civilians. In fact eye safety is so important that performance degradations may be necessary in order to meet these objectives.

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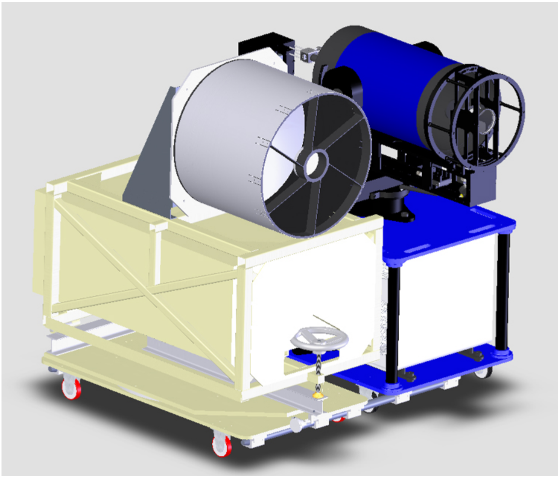

Figure 1. Model of TREDS-2 TEPS/Raman System

Figure 2. Picture of TREDS-2 in field test.

The selection of the laser wavelengths has a major impact on system performance and "eye safety". A tradeoff analysis was performed and the main YAG wavelength was selected as 266nm because:

- $1/\lambda^4$ Raman Enhancement: As compared to 532nm excitation, the Raman signal from a 266nm laser should be 16x greater.
- TEPS Enhancement: With the TEPS technique, the plasma from a LIBS event is enhanced by 25-300x.
- Increased Eye Safety: Per ANSI Z136, the Maximum Permissible Energy (MPE) of a 266nm laser is ~1000 times greater than that of a 400-1100nm laser, see figure 3.
- The wavelength is attenuated by most all binoculars and other magnifying optics, thus the Nominal Ocular Hazard Distance – Magnified (NOHD-M) is undefined or at worst case the same as the NOHD.

Changing form the 1064nm fundamental Nd:YAG fundamental to the 266nm 4th harmonic does result in a ~10x reduction of the peak laser energy. Fortunately the previously mentioned signal enhancements more than compensate for this. This balancing of Eye Safety with performance has resulted in a system which has a reasonable NOHD and energetic detection. The NOHD for the TREDS-2 system is ~2.5x the standoff range for TEPS and ~5x the standoff range for Raman (i.e. for a standoff range of 20m, the NOHD for TEPS is ~50m and ~100m for Raman).

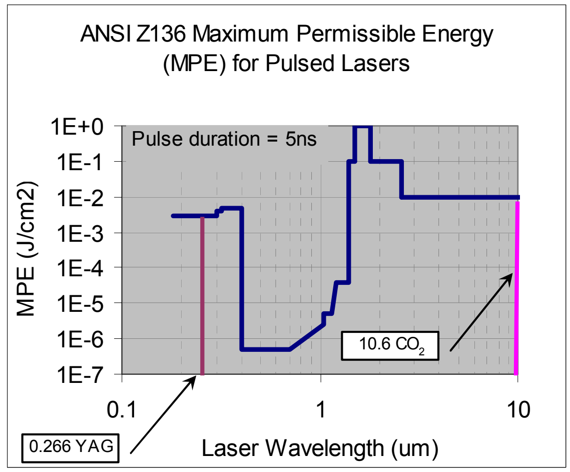

Figure 3. ANSI Z136 MPE for pulsed lasers. The TREDS-2 system wavelengths are identified.

3. RESULTS

3.1 LIBS Results

A comparison of the signal amplitude between a LIBS plasma and TEPS plasma on a bare Al substrate is shown in figure 4. Several of the key lines have been identified and the signal enhancements range from 5-500x. The difference between these signal enhancement factors and those previously reported (Killinger et al., 2007) is due to test conditions—mainly CO_2 energy density. In the past, the CO_2 focusing lens close to the sample (~10 in) and the CO_2 energy density was relatively high. In this case the entire system was at a 20m standoff range and the CO_2 energy density is slightly less thereby producing different enhancement factors.

Figure 2 shows the raw spectroscopic TEPS spectra from Ammonium Nitrate which was evaporated on a black 55 gal drum lid and sampled at 20m range. The medium and low concentration data have some unique peaks that are easily distinguishable from the black drum lid.

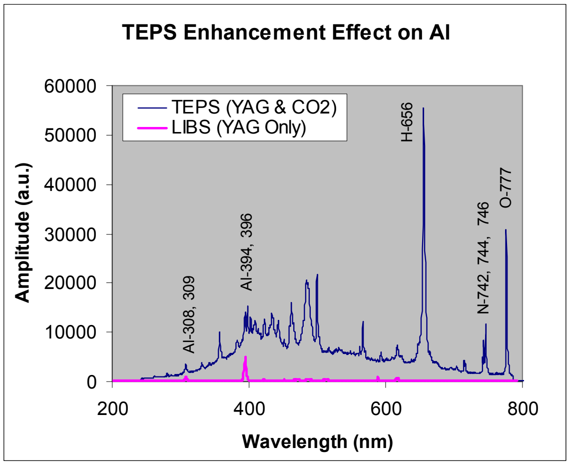

Figure 4. Comparison between LIBS Plasma and TEPS Plasma for bare Al Substrate at 20m range.

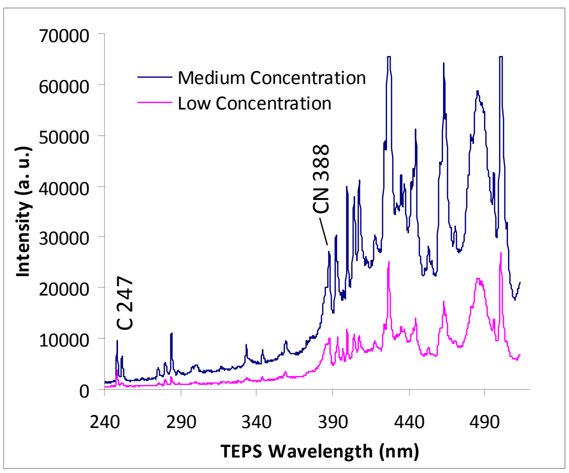

Figure 5. TEPS results of AN on a 55 gal black painted drum lid. Standoff range was 20m.

3.2 Raman Results

Figure 6 shows the raw spectroscopic Raman data from Ammonium Nitrate (AN) which was evaporated on a black 55 gal drum lid and sampled at 20m range. The AN is easily distinguishable by the 1050cm^{-1} peak. The contributions from the atmospheric Oxygen and Nitrogen can be seen at 1550cm^{-1} and 2330cm^{-1} respectively. As would be expected the High concentration data is easily distinguishable while the low concentration is below the detection limit for these operating conditions.

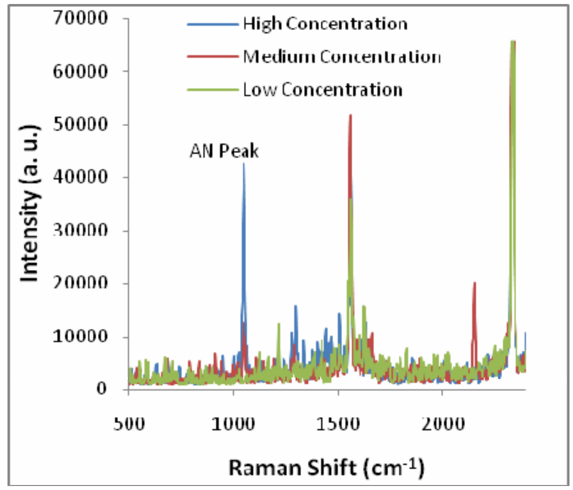

Figure 6. UV Raman resutls of AN on a 55 gal black painted drum lid. Standoff range was 20m

3.3 Data Fusion

One of the most unique features of the TREDS-2 is the integration of TEPS with the Raman spectroscopic technique into a single system. Typically, Raman requires somewhat high concentrations of explosives to be an effective analysis tool, which makes it perfect as a complementary technique to TEPS, which is useful for the low concentration analysis of explosives. Thus, the concentration range over which the system is able to operate is greatly expanded by two techniques.

4. CONCLUSION

The TREDS-2 system integrates TEPS and Raman laser detection techniques for standoff detection of explosives. This system has been demonstrated in the field at standoff distances of up to 20m. The TEPS approach provides design margin over conventional LIBS analysis thereby allowing a single UV laser to be used for both techniques while also minimizing the Eye Safety implications.

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