Fastest-In-Class **Explosive Detection** Using RamTest™ Raman Identifier

INTRODUCTION

Data from Global Terrorism Database shows that number of terrorist attacks utilizing explosive devices has dramatically increased within last decade **(1)**. Numerous analytical methods, including portable Raman, have been developed to enable detection of explosives, their precursors and / or breakdown products at the field **(2)**. In this application note, it is directly demonstrated that **RamTest-CSI™ Handheld Raman Identifier** (Figure 1) enables fastest-in-class ID of explosive materials (among handhelds), identification and quantitation of individual components in mixtures, as well as ability to analyze compounds previously considered impossible or hard-to-detect using handheld Raman (examples: ammonia, ammonium nitrate, RDX, biologics). Other CSI applications include but not limited to counterfeit testing (medicine, food, beverages or alcohol products), analysis of biological stains, etc.

WHY RAMTEST-CSI™ IDENTIFIER?

RamTest-CSI™ Handheld Raman Identifier is specifically developed to enable best-in-class performance (among handhelds) for CSI, HazMat, and Homeland Security applications. The superior performance is achieved by combining 532 nm Raman excitation (non-conventional for handheld Raman) with the state-of-the-art methodology to reduce impact of fluorescence on Raman measurements. Unique techno-economic benefits of **RamTest-CSI™ Handheld Raman Identifier** for CSI / HazMat / Homeland Security applications include:

Figure 1. RamTest-CSI™ Handheld Raman Identifier.

Attachments (bottom right) enable measurements of liquids and solids on any surface 'as is'; on a slide; or through containers: vials, bottles, jars, evidence bags, blister packs, etc.

- **~2-fold reduced instrument costs** due to engineering / economic advantages that use of 532 nm light offers.
- **User-updatable database of ~200 explosives and narcotics**
- **5 and 16 times faster analysis** than that for conventional portable Raman units using 785 and 1064 nm excitation, respectively. This is because Raman signal intensity is inversely proportional to 4th power of laser excitation wavelength, $I_{RAMAN} \sim (1/\lambda_{EX})^4$.
- **ID / Quantitation of individual components in complex mixtures** (clandestine substances mixed with camouflaging compounds)
- **Reduced detection limits with improved analysis accuracy.** Ability to analyze what **was not possible for handheld Raman**. Examples: ammonia, biologics.

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- **Safe detection of explosives** by using up to 5 and16 fold reduced laser power compared to conventional 785 and 1064 nm instruments, respectively, **without compromising analysis quality**.
- **Ability to analyze** liquids or solids/powders **on any surface 'as is'**, or **directly through containers:** evidence bags, vials, bottles, jars, Petri dishes, blister packs, etc.
- **Unmatched combination of spectral resolution (~4 cm^{-1}) and spectral range (~120-4000 cm^{-1})** due to higher dispersion of 532 nm light, which gives engineering advantage in space-limited handhelds.
- **SERS substrates available**

EXPERIMENTAL

All samples were analyzed using a **RamTest-CSI™ handheld Raman Identifier** (BioTools, Inc., Jupiter, FL, USA) shown in **Figure 1**. All tests were run in automated mode (requiring no prior knowledge of Raman spectroscopy), where all measurement parameters are automatically adjusted to optimize signal-to-noise ratio and minimize fluorescence, with remaining fluorescence background (if any) automatically subtracted. RamTest™ software is CFR 21 compatible and comes with a user-editable database to conform all needs.

RESULTS

Figures 2A and 2B directly demonstrate the superior performance of 532 nm **RamTest-CSI™ handheld Raman Identifier** to enable fastest-in-class, reliable and safe detection, ID and quantitation of explosives. It should be noted that some of shown explosives / precursors are considered to be either "strongly fluorescent" (dinitronaphthalene) or "hard to detect" using a handheld Raman (RDX, ammonia, and ammonium nitrate). Yet, **RamTest-CSI™ reliably IDs all the shown compounds within only 1-5 seconds!** Such a fast and reliable detection is a direct result of 5-16 times stronger Raman signal at 532 nm excitation compared to those at 785 and 1064 nm.

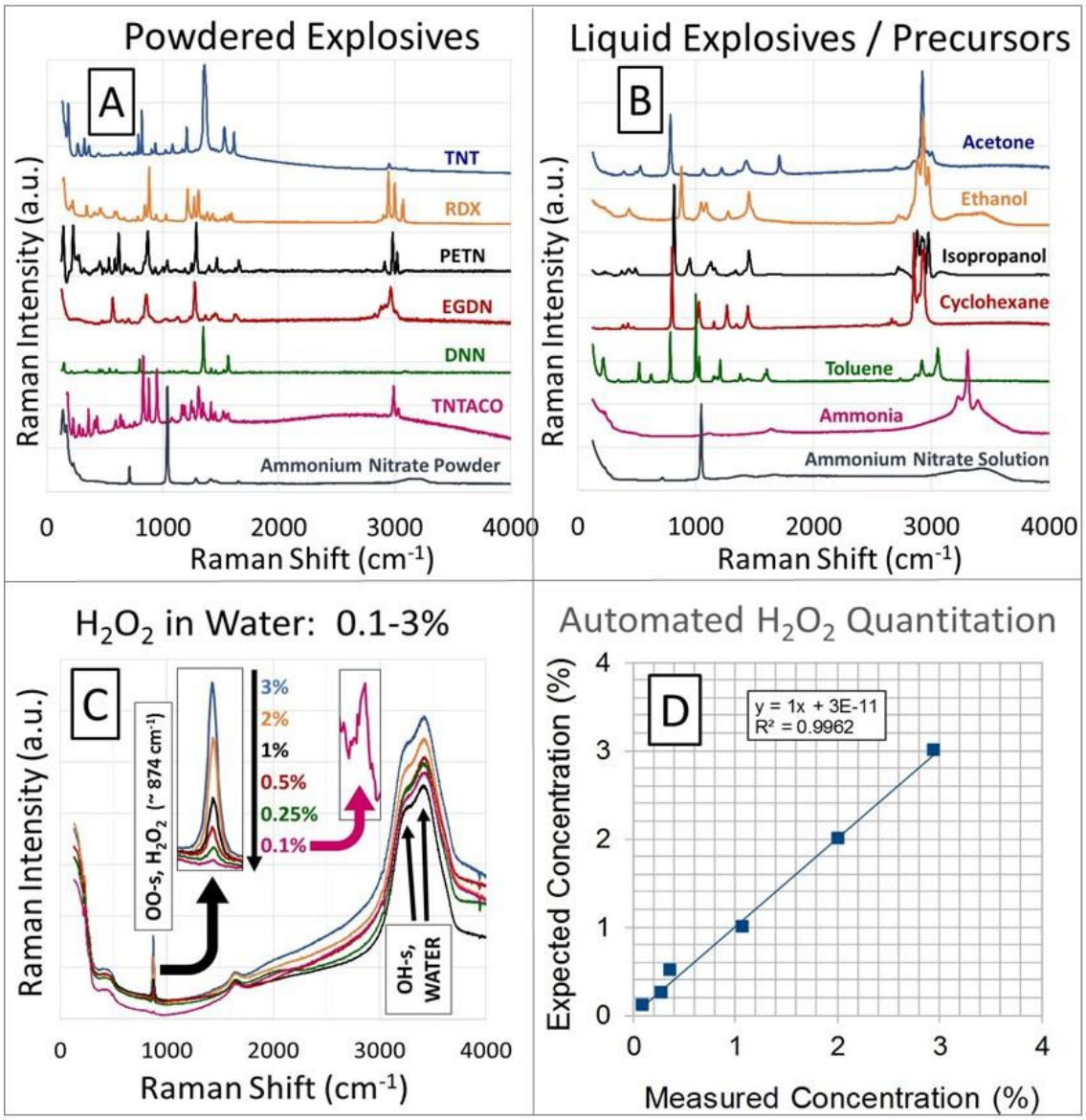

Figure 2. Spectra of Explosives Measured by a 532 nm RamTest-CSI™ Handheld Raman Identifier (BioTools, Inc).

A) Powdered explosives. **B)** Liquid explosives / precursors. **C)** Hydrogen peroxide (H_2O_2) solutions in water, 0.1-3%. Insets show magnified ~874 cm^{-1} OO-stretching hydrogen peroxide band. **D)** Automated hydrogen peroxide quantitation using 3200-3400 cm^{-1} OH-stretching water bands (unattainable with today's commercial 785 or 1024 nm handhelds).

In addition, stronger dispersion of 532 nm light compared to that at 785 or 1064 nm gives engineering advantage in space-limited handhelds to provide **RamTest-CSI™** with a superior combination of **widest-in-class spectral range** (100-4000 cm^{-1}) **but still best-in-class spectral resolution** (4-6 cm^{-1}). This directly enables new applications for handheld Raman including automated quantitation of analytes in aqueous solutions. Figure 2D directly demonstrates automated hydrogen peroxide quantitation in water down to <0.1%. Specifically, ca. 3200

– 3400 cm^{-1} OH-stretch bands of water, which are unattainable with today's commercial 785 and 1064 nm handhelds, were used as internal intensity standards (Figure 2C).

CONCLUSIONS

Our analysis indicates that **RamTest-CSI™ Handheld Raman Identifier** (BioTools Inc., Jupiter, FL, USA) shows superior performance for CSI, Homeland Security and / or HazMat applications. Such a superior performance is achieved by combining 532 nm Raman excitation (non-conventional for handheld Raman) with the state-of-the-art methodology to reduce impact of fluorescence on Raman measurements.

Identified **RamTest-CSI™** techno-economic benefits include ~2-fold reduced instrument cost, up to 5-16 times faster analysis for a great deal of practical field applications, reduced laser power (enabling safe detection of explosives, reduced laser safety concerns or laser-induced sample degradation, as well as extending battery continuous operation time), superior performance in water and most of organic solvents, ability to analyze substances 'as is' and through a large variety of glass and plastic containers (including amber), improved combination of spectral range and spectral resolution, as well as reduced detection limits with improved analysis accuracy.

As a result, 532 nm **RamTest-CSI™ Handheld Raman Identifier** can dramatically improve business case for a significant fraction of practical field applications and / or extend the applicability scope of handheld Raman to new fields. Best applications include but not limited to counterfeit biologics, rapid detection of explosives, ID of individual components in complex mixtures, automated quantitation of analytes in aqueous solutions, diluted analytes in water or organic solvents, and reliable detection of several compounds previously considered "hard to detect" using handheld Raman devices (examples: ammonia, biologics, RDX, ammonium nitrate).

REFERENCES

(1) Open source, *Global Terrorism Database*, http://www.start.umd.edu/gtd (2015)

(2) K. L. Gares, K. T. Hufziger, S. V. Bykov, and S. A. Asher, *J. Raman Spectrosc.*, **47**, 124–141 (2016)