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14. ABSTRACT

Under this contract, ARA provided support to USASOC and the rest of the scientific community through direct or subcontracted efforts. For USASOC, ARA provided support for 8 student interns over 2.5 summers. We also provided support to scientists traveling and support research in various efforts such as anthropological studies, bio sensors, textiles, and robotics.

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USASOC, Student Support, Scientific Research, Scientific Support

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Report Title

Final Report: USASOC Engineering and Analysis Support

ABSTRACT

Under this contract, ARA provided support to USASOC and the rest of the scientific community through direct or subcontracted efforts. For USASOC, ARA provided support for 8 student interns over 2.5 summers. We also provided support to scientists traveling and support research in various efforts such as anthropological studies, bio sensors, textiles, and robotics.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received	Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
John Manor	0.20	
Kevin Kijowski	0.20	
FTE Equivalent:	**0.40**	
Total Number:	**2**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Maggie Barns	0.20	Graphics Arts
Ben Stewart	0.20	Mechanical Engineering
Ryan Burk	0.20	Mechanical Engineering
Andrew Trull	0.20	Mechanical Engineering
Cody Rogers	0.20	Mechanical Engineering
Colinda Petrus	0.20	Mechanical Engineering
FTE Equivalent:	**1.20**	
Total Number:	**6**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

1 a. Nomadics, Inc
1 b. 1024 S. Innovation Way

Stillwater OK 74074

Sub Contractor Numbers (c): CSA-000735.014.FLIR
Patent Clause Number (d-1):
Patent Date (d-2):
Work Description (e): Pursuant to our discussions during the month of August 2011, Nomadics, Inc. agrees tosu
Sub Contract Award Date (f-1): 8/15/11 12:00AM
Sub Contract Est Completion Date(f-2): 9/30/11 12:00AM

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1 a. NORTH CAROLINA STATE UNIVERSITY
1 b. 2901 Sullivan Drive

Raliegh NC 276957514

Sub Contractor Numbers (c):
Patent Clause Number (d-1):
Patent Date (d-2):
Work Description (e):
Sub Contract Award Date (f-1):
Sub Contract Est Completion Date(f-2):

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Patent Clause Number (d-1):
Patent Date (d-2):
Work Description (e):
Sub Contract Award Date (f-1):
Sub Contract Est Completion Date(f-2):

Inventions (DD882)

Scientific Progress

See attachment for scientific progress details

Technology Transfer

Annual Report for W911NF-10-C-0071 – December 18, 2013
James Kainz

Scientific Accomplishments

UNC/USASOC Defense Applications Group Support

- Provided classified processing and clearance support to 12 members of UNC General Administration for work at USASOC
- Participated in meetings when applicable to support USASOC Intern Program

USASOC Intern Program

- Provided support to UNC summer students for onsite work at USASOC
- In this program, students are identified to work in various activities including human performance, engineering, and graphic design.
- Support to 8 interns over three summers
    - 1st Summer – Colinda Petrus (WCU – Engineer)
    - 2nd Summer – Cody Rogers (WCU – Engineer) and Andrew Trull (WCU Engineer)
    - 3rd Summer - John Manor (UNC – Physiology), Kevin Kijowski (App State – Sports Medicine), Maggie Barns (NCSU – Graphics Arts), Ben Stewart (WCU – Engineering), and Ryan Burk (WCU – Engineering)
- All interns were paid an hourly wage
- All interns were provided temporary housing stipend

Biosensors Program

- Supported scientist travel and research to South Africa for work on elephant training and initial project development (Kip Schultz from Nomadics).
-

Scientific Support

- Provided scientific support to Dr. Sarah Cowie and Christopher LeBlanc to study archeological significance of tribal interactions with western military installations.
- Canine meeting support for several scientists.

NCSU Textile Prototype Research

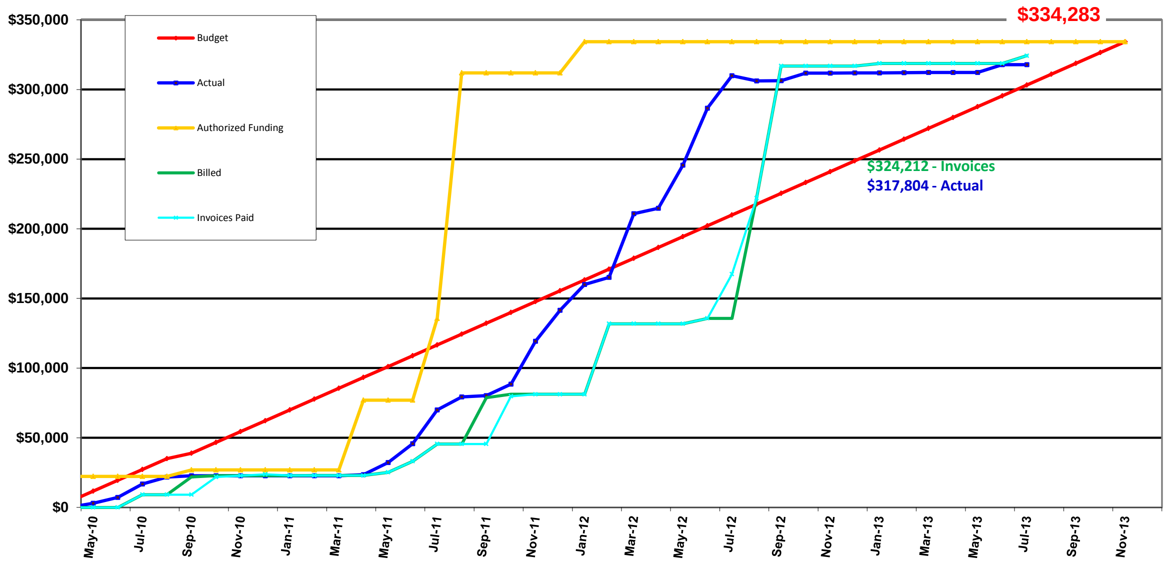
- Supported a study to examine a proof of concept for chemical and radiation detection using a corona discharge driven by a textile-embedded electrode array (final report attached)

Schedule

- All tasks completed. Project was finalized in December 2013.

Funding Status

- All charges have been completed –(see final funding profile below).
- Final total charges against this project are $334,058.56



A proof of principle study: Chemical and radiation detection using a corona discharge driven by a textile-embedded electrode array

A final report prepared by:

Steve Shannon and Warren Jasper
North Carolina State University
Raleigh, NC 27695

4 November 2013

This white paper details research carried out in a collaborative effort between the NC State Department of Nuclear Engineering and Department of Textiles to evaluate an embedded electrode textile developed by the Jasper research group to generate an electrically active corona discharge for the purpose of detecting chemicals and radioactive isotopes. The scope of work detailed here includes design and test of a portable prototype system for a systematic study whereby the prototype system is exposed to an aerosol of acetone or IPA and the measurement of the electrical and spectral characteristics of the corona discharge that may provide quantitative measurement of the presence of organic solvents. Experiments conducted on this prototype did yield measurable changes in optical emission in the presence of organic solvents with respect to emission intensity. However, these emission signatures did not correlate to specific solvent type or concentration and were instead attributed to changes in ionization patterns in the vicinity of the corona discharge. Use of the corona source as a radiation monitor was evaluated from a theoretical basis and determined to be non-competitive as a low cost radiation monitor due to its very low sensitivity to reasonable ionizing radiation levels. In summary, initial proof of principle studies did not yield results that would warrant further investigation unless a transformational method in either corona formation or electrical and optical detection were also proposed.

Introduction

This effort centers on the application of a flexible textile based electrode array that can generate a large area corona glow uniformly over the textile surface. This electrically active glow region is very sensitive to surrounding conditions including gas composition and external ionizing sources. Motivated by this, the PI's proposed a proof-of-principle study where this technology is evaluated as a chemical and radiation detector. In this inception, changes to the glow characteristics from light emission and electrical impedance will be measured with respect to chemical/radiation exposure to determine the sensitivity of this device for chemical and radiation detection applications.

The primary device that was characterized is a woven fabric with embedded high voltage electrodes that can produce a uniform corona glow discharge over the surface of the textile. The basic structure is a woven fabric of insulating fiber. Evenly spaced across the surface of the fiber is an array of conducting wires that are alternately biased positive and negative to produce a high field condition uniformly along the surface of the textile. This establishes the conditions to form a low density corona glow over the surface of the textile.[1] A schematic of this structure is shown in Figure 1. A photograph of a sample of this textile fabricated for this study is shown in Figure 2.

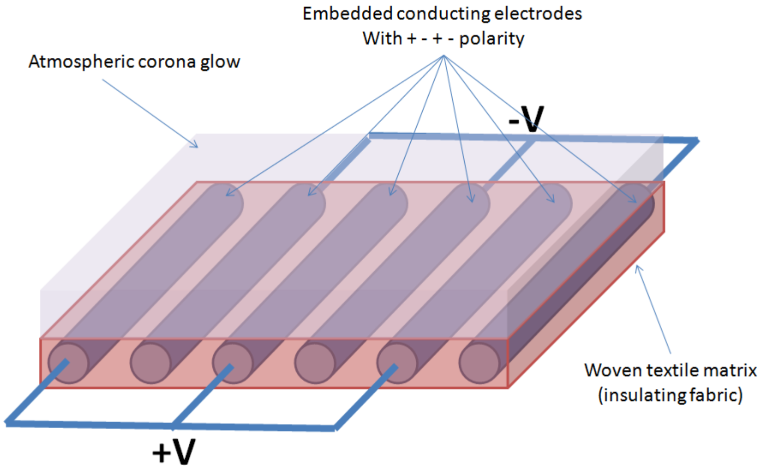


Figure 1 – schematic of the textile electrode array

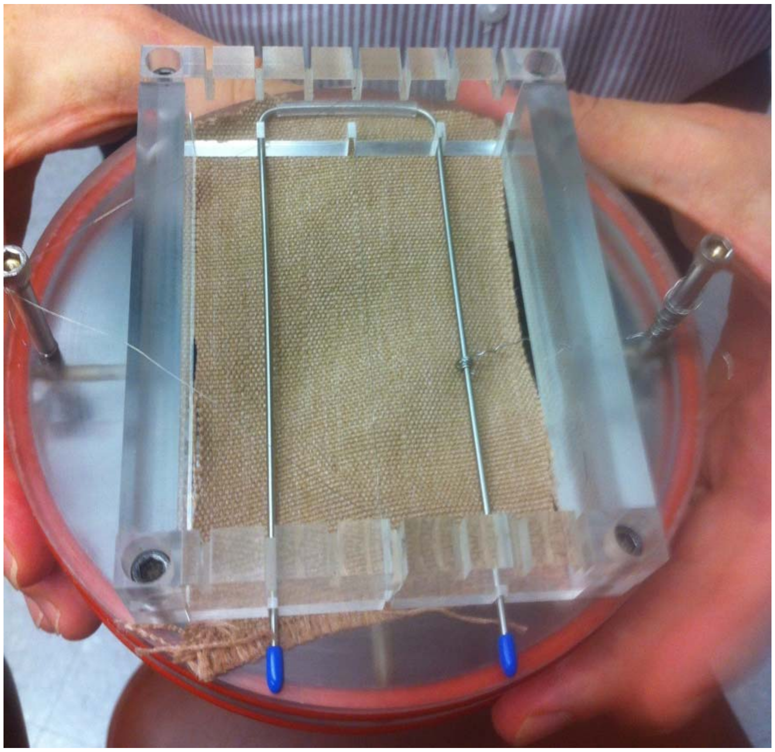


Figure 2 - Woven textile with embedded conducting electrodes for corona discharge formation. The sample is fixed on a text jig for mounting in an experimental configuration to test sensitivity to VOC for detection purposes.

The corona glow presents two pathways for detection of anomalies in its surrounding environment. The first pathway is the light emission from the corona by specie excitation due to electron impact. The intensity of light emission for a given transition, assuming that electron impact excitation dominates the production of the excited state, is given by

$$I(\hbar\nu) = n_g \int_0^\infty f(E) \sqrt{\frac{2E}{m_e}} \sigma(E) dE$$

where I is the intensity of light emitted with characteristic energy $\hbar\nu$, n_g is the background density of the ground state specie that is excited via electron impact, $f(E)$ is the electron density distribution with respect to energy E, m_e is the electron mass, and $\sigma(E)$ is the energy dependent electron impact excitation cross section. Charged species, particularly via β decay, may contribute to increased emission, particularly of otherwise low probability excitations due to their high energies compared to the bulk electrons populating the corona discharge. Likewise, these energetic species can form electron-ion pairs in the corona glow. This supplemental formation of charged species influence the conductivity of plasma between adjacent electrodes by increasing the bulk electron density, increasing mobility driven conductivity by

$$\sigma = e n_e \mu_e$$

where μ_e is the electron mobility, which is relatively constant in the presence of a weak radiation source and σ is the DC conductivity of the discharge. The current density J between the electrodes is related to the electric field between the electrodes E by the relationship $J = \sigma E$. Accounting for geometry, this provides a direct link between the DC characteristics of the plasma (Ohm's Law), and charged particle density. If a radiation source provides sufficient ionization to modify σ, it is hypothesized that the corona glow can be used for radiation detection.

Corona discharge radiation detection

Ultimately, the detection of radiative nuclear species such as decaying nuclides or neutrons using this corona system is desired. In the case of radioisotopes, direct modification of the corona discharge's electrical and optical properties by incident radiation would be utilized for specie detection. In this inception, a radionuclide emits ionizing radiation in close proximity to the corona discharge. The ionizing specie (α, e^-, e^+, γ or x-ray) is emitted and interacts with gas species contained within the corona discharge. These species then excite or ionize particles in this electrically active region, generating an electrical or optical signature that can fingerprint the radiation event. A schematic of this direct measurement concept is shown in Figure 3. Neutron detection would require an intermediate reaction such as radiative capture. To facilitate this, the textile fabric would need to be impregnated with absorbing material (such as gadolinium, boron, etc.) that will then produce a photon and preferably a short lived β or α emission due to nuclear de-excitation and isotope decay. A schematic of this two step process is shown in Figure 4. In this inception, the impregnated material must have a sufficiently large thermal neutron capture cross section and must generate a short half life isotope that decays via β or α decay. This subsequent decay is the event that generates electrical or optical signature in the corona discharge that may provide a means for neutron detection.

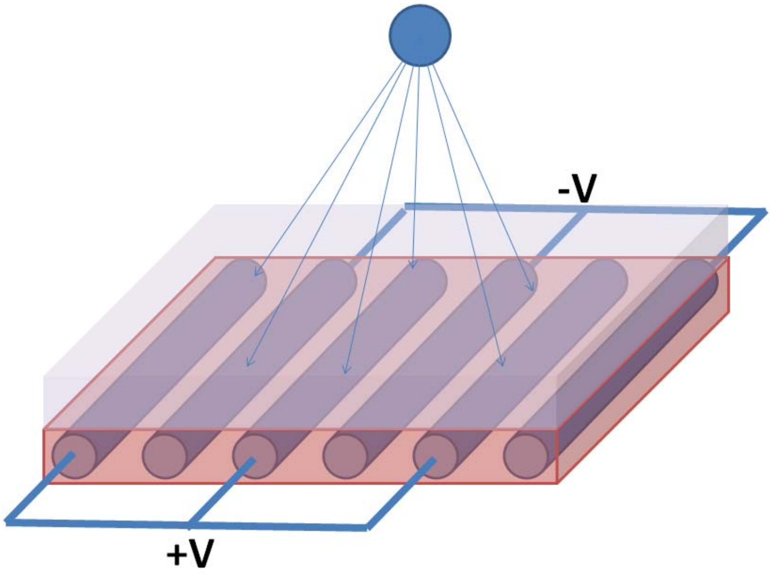


Figure 3 - simplified low barrier approach for studying radiation effects on large area corona glow properties

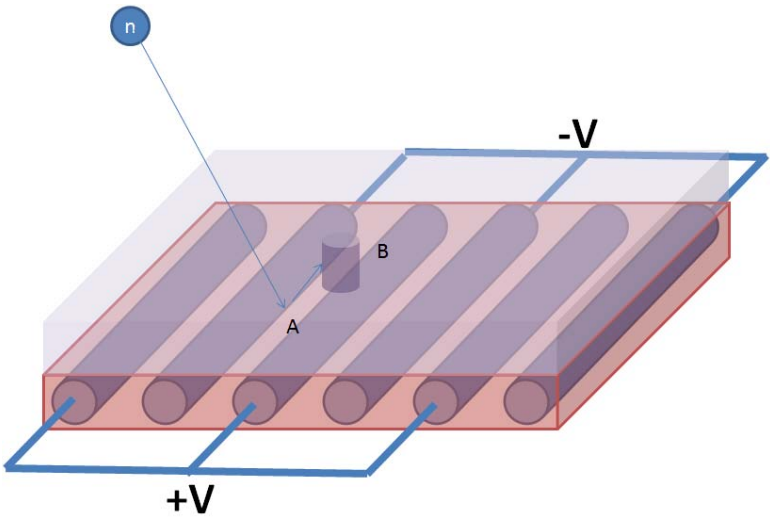


Figure 4 - neutron detection via neutron absorption and subsequent decay (A) of impregnated textile material to manipulate the optical and electrical characteristics of the corona discharge via charged particle interaction in a small plasma volume (B)

The depiction of Figure 4 presents several practical challenges for direct demonstration of this technology as a neutron detection system. Specifically, the incorporation of new materials into the textile weave for sufficient neutron absorption presents a long lead-time high cost proof of concept pathway. Several isotopes have the combined characteristics of stability, high absorption cross section, and short product half-life via charged particle emission for this application. One such isotope is dysprosium-164 (^{164}Dy). ^{164}Dy has a thermal neutron cross section of 2650 barn. The isotope generated via neutron absorption, ^{165}Dy, decays via β^- conversion with a half life of 2.3 hours. Assuming a 1mm thick woven textile with 10% ^{164}Dy incorporation, a 10^{10} $m^{-2}s^{-1}$ flux of thermal neutrons will produce approximately 10^{10} ^{165}Dy isotopes per square meter per second; this results in a final activity of approximately 10^{10} β- decays per second per square meter with a rise time of approximately 8 hours due to the half life of ^{165}Dy. With the corona, assuming a 200ns discharge decay time, approximately 10^{18} electron-ion pairs are generated via electron impact excitation and photoionization in the same area to maintain a nominal 10^8 cm^{-3} discharge approximately 5mm thick.

In comparing the charged particle production due to β- decay of ^{165}Dy to the charged particle production rate necessary to sustain a moderate density corona discharge over the same surface area, it is unlikely that a measurable change in the electrical signature of the corona discharge will be detected. Using the scaling laws of dc conductivity, electrical drift due to non-radiative processes such as humidity, barometric pressure, and room temperature would have a substantially greater impact than that seen for b emission from the textile surface. Optical emission generated by excitation from the high energy electrons emitted would produce light that could be measured. However, there is no inherent characteristic of the corona discharge that enhances this light emission or provides a pathway for radiation measurement.

When compared to more common radiation detection systems that utilize direct electrical modification of gases such as Geiger-Mueller tubes, corona discharge based detection schemes would be expected to have much lower sensitivity and greater variability. The sensitivity of a corona based detection system will be diminished due to the absence of a cascade-type amplification of induced ionization current due to the reduced fields formed in a corona discharge compared to the rarefied ionization operating regime of a G-M tube. Additionally, ion recombination, quenching, and negative ion formation in air and humid-air type discharges inhibit amplification of ionization signature and reduce signal magnitude. With regard to sensitivity, since changes in humidity, air composition, or gas temperature can generate similar electrical and optical signatures, this detection method would require significant redesign to minimize “false positive” readings due to these more benign changes in air composition.

Corona discharge chemical detection

Ultimately, the detection of chemical agents for nonproliferation verification is desired. In order to accomplish this, it is envisioned that the textile fabric could double as a filter on the discharge side of a chemical plant or process as well as serve as a detector for organic solvents. When organic solvents are ionized, as when they come into contact with the plasma, they should emit photons at characteristic frequencies that can be analyzed with a fiber-optic spectrophotometer. The major issue is whether or not enough signal can be generated in an atmospheric plasma in high enough densities to detect the presence of organic solvents or other chemical agents. To improve the signal to noise ratio, multiple signals from multiple fibers will be summed or combined.

A test fixture, whereby air combined with volatile solvents is passed through the textile electrode, was constructed to study the sensitivity of this device to airborne chemical species. Electrical and optical properties of this discharge were measured using electrical probes and VIS/NIR optical emission spectroscopy. The excitation of molecular bands in organic solvents, such as IPA and acetone were measured to evaluate the system’s ability to detect volatile gas phase components.

A schematic of the test configuration is shown in Figure 5. A photograph of the text fixture in operation is shown in Figure 6. Wire electrodes were biased to a 1300V differential potential. 5 slm of clean dry air was passed through a bubble chamber filled with either isopropyl alcohol or acetone and then fed directly into the enclosed test chamber. An Ocean Optics VIR spectrometer was trained on the corona region using a 200 micron diameter single core fused silica fiber. Discharge current was monitored using an in-line low noise current amplifier. Four conditions were measured:

- 5 slm clean dry air (CDA) – this was used as the baseline measurement for electrical and optical analysis.
- 5 slm CDA bubbled through isopropyl alcohol
- 5 slm CDA bubbled through acetone
- 5 slm CDA with direct application of IPA onto the textile surface – this was not intended to be a realistic comparison of operating conditions but instead a demonstration of the levels of VOC’s that would need to be present to obtain a reasonable electrical or optical signature for detetion.

In all cases run, electrical current did not demonstrate any measurable deviation when compared to the baseline CDA condition. Measurement of optical emission as a function of wavelength showed an overall increase in emission intensity across the dominant molecular nitrogen bands compared to the CDA baseline. A comparison of measured spectra is shown in Figure 7. Spectra normalized to the integrated intensity over the dominant molecular nitrogen bands between 284nm and 436nm are shown in Figure 8. Only in the instance where IPA was directly applied to the textile did additional emission bands manifest. In this instance the molecular nitrogen bands in the 600nm and 700nm range. None of the conditions run produced emission spectra directly from the solvent. In a separate experiment, air flow was transitioned from 5slm CDA to 5slm CDA with IPA. The emission intensity of the dominant bands between 284nm-436nm (Band 1) and 635nm-778nm (Band 2) was tracked as a function of time. IPA was introduced to the system from 0 seconds to 110 seconds, at which point the IPA source was cut off. The results are shown in Figure 9. Tracking both bands demonstrates that the intensity change with the introduction of IPA is global; the change in intensity magnitude is identical for both cases.

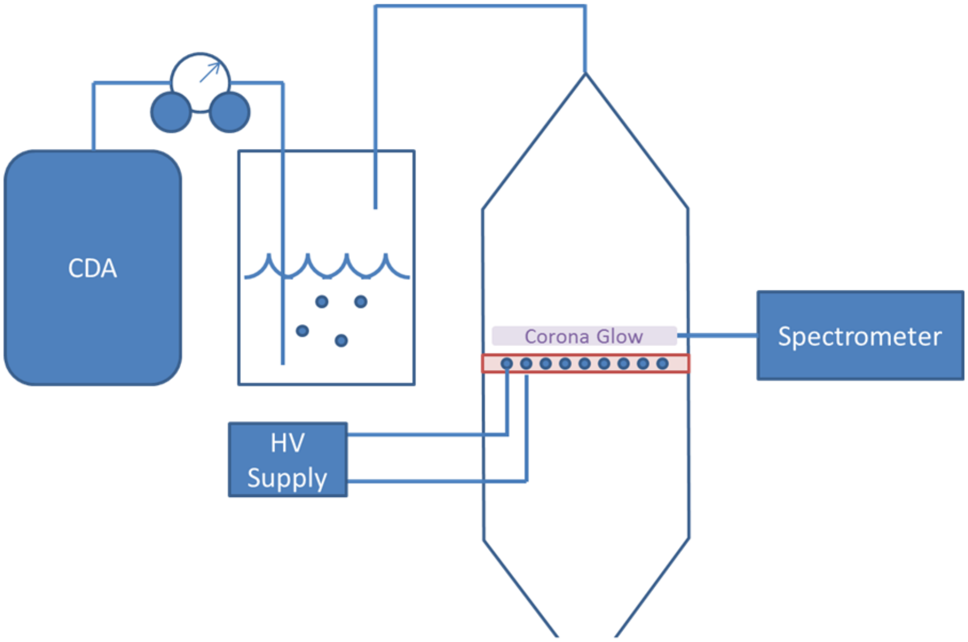


Figure 5 – Experimental test bed for chemical detection with embedded corona textile concept

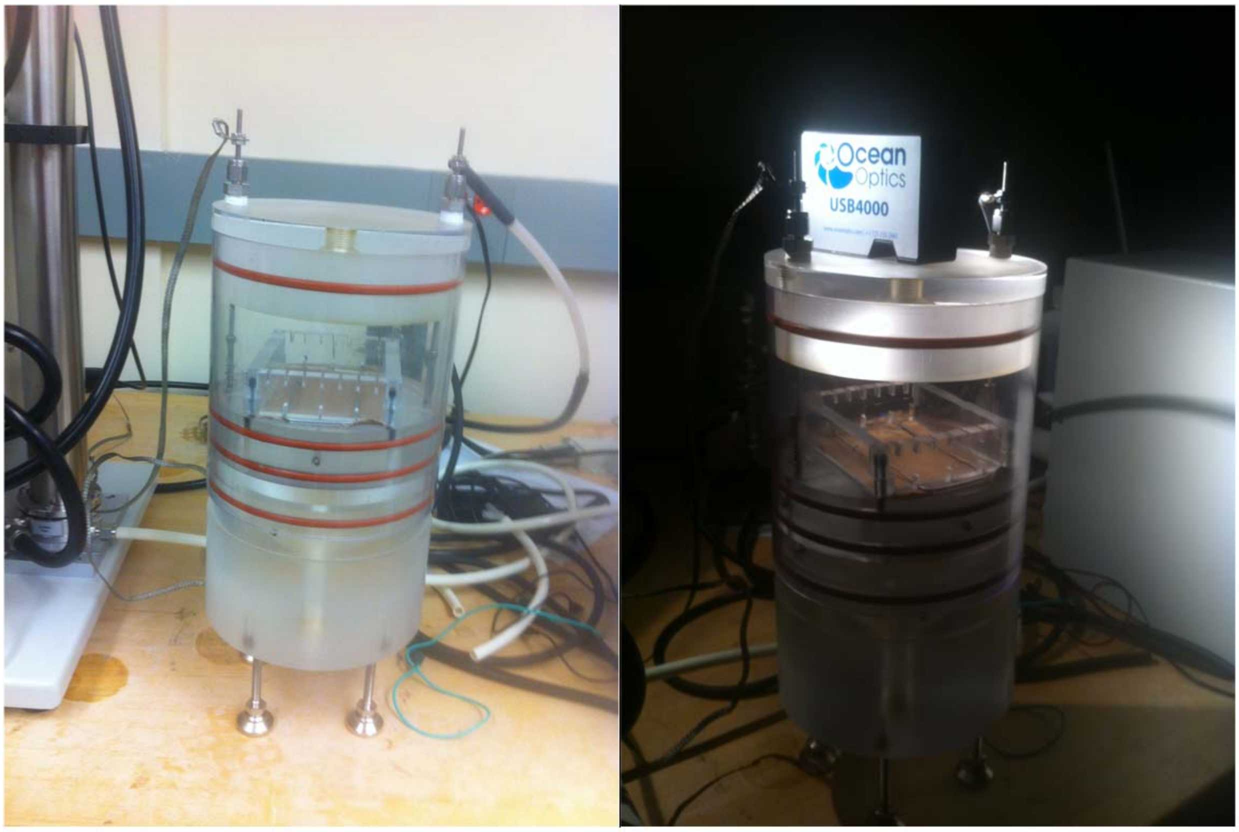


Figure 6 - Experimental configuration for chemical testing

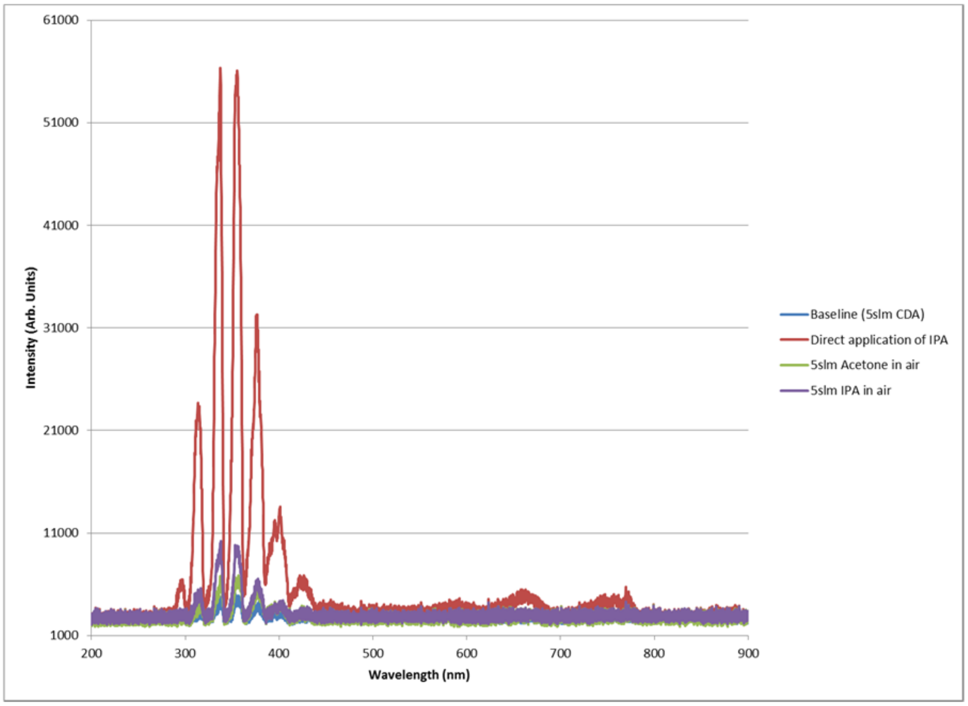


Figure 7 - measured emission spectra for four test cases

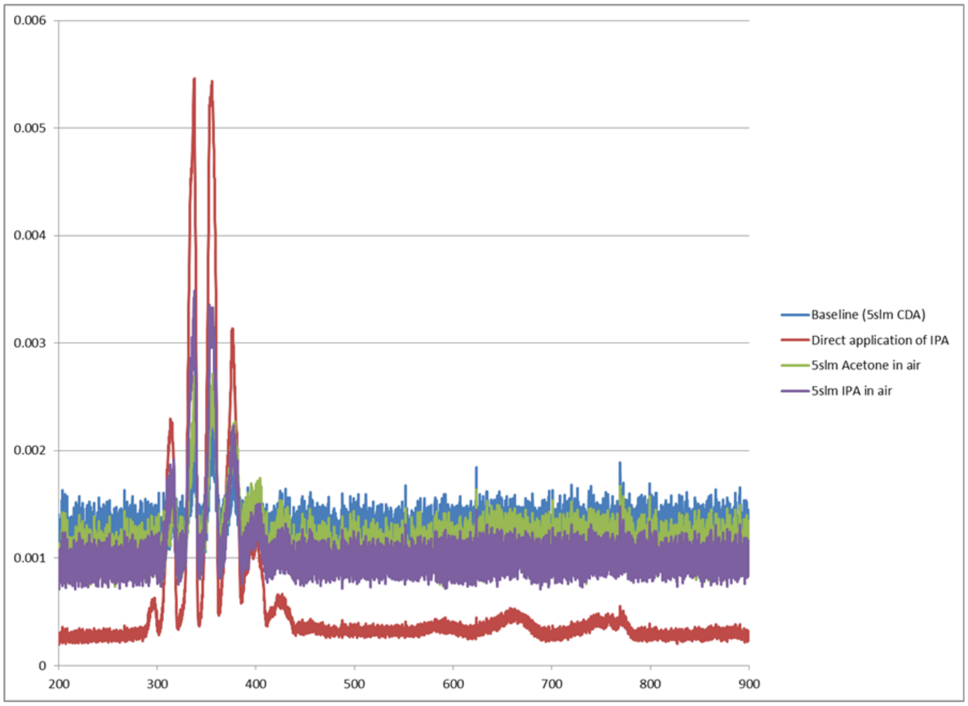


Figure 8 - Normalized spectra. Note that the inclusion of gas phase solvents do not generate any new emission peaks, but instead appear to only impact the intergrated intensity or brightness of the plasma as a whole.

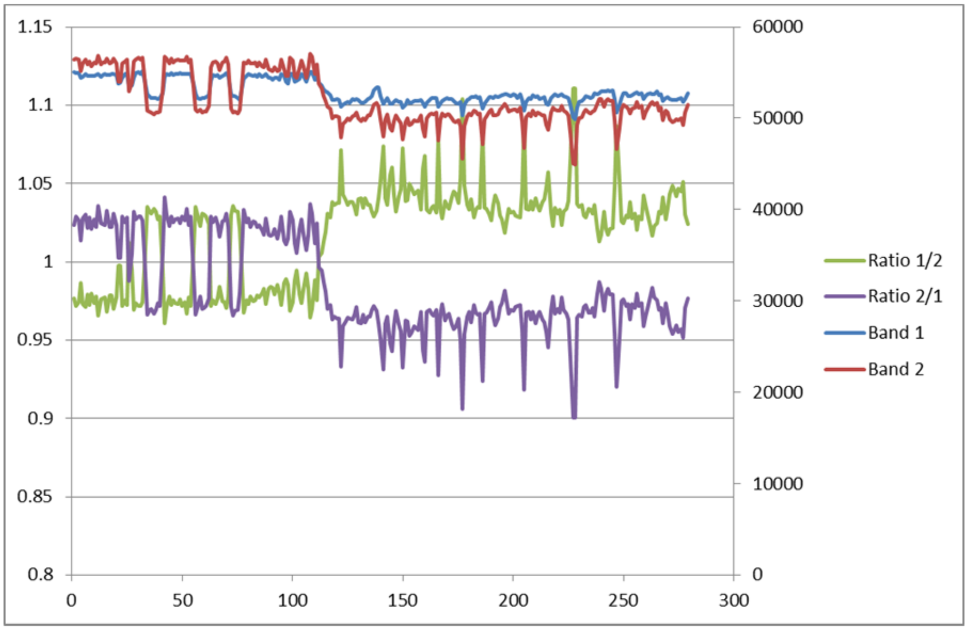


Figure 9 - Intensity as a function of time for IPA injection tests. IPA was run through the system until 110 seconds, at which point the flow was 100% CDA.

Summary of results and recommendations

Summarizing the deliverables for this project and the outcomes of our experiment:

Deliverable #1 – quantification of the feasibility of detecting the presence of IPA or acetone using emission spectroscopy. IPA and acetone do impact the global emission intensity of the corona glow. However, chemistry specific signatures are not obtained when the spectra is analyzed as a function of wavelength. Based on these results, we conclude that **use of an embedded electrode textile driven corona discharge for chemical detection is not feasible without a transformative improvement in detection.**

Deliverable #2 – quantification of electrical and optical signatures in the presence of controlled alpha, beta, and gamma radiation sources. These signatures include DC current shift, current spikes, global emission, and spectroscopic emission analysis. A theoretical calculation of the impact of radiation sources on corona electrical and optical properties predicts that **a corona glow will not sufficiently respond to the presence of nominal radiation fields either optically or electrically to provide any additional sensitivity to existing radiation detection technologies such as GM tubes.**

Deliverable #3 – a recommendation as to the viability of this system as a chemical detector. Assuming that the system is viable, a proposed system that could work as a filter as well as a chemical detector for nonproliferation verification. **Based on the results of deliverables one and two, we conclude that this system as proposed is not a viable pathway for detection of chemical and radiological hazards. Transformative advances in either source design or detection would be required for this technology to be viable.**

References

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[1] S.C. Brown (1959) *Basic Data of Plasma Physics*; John Wiley and Sons Inc., New York