Contract No:

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High-Sensitivity Electric Field Detection Based on Gas Polarization

Project highlight. The Emergency Response community would greatly benefit from a diagnostic tool capable of determining the state of charge of a high-voltage source. The goal is to develop a tool for detecting an electric field using the depolarization effects imposed by the self-assembly of gas molecules influenced by dielectrophoretic forces.

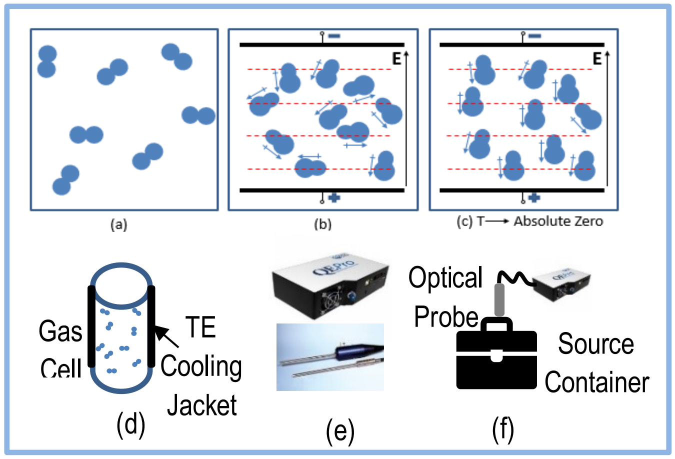

***Figure 1:** Top- Effect of electric field on a gas molecule. Lower- schematic of proposed sensor design.*

Awards and Recognition

NA

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publicly published in its current form.

SRNL Legal Signature

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Signature **Date**

High-Sensitivity Electric Field Detection Based on Gas Polarization

Project Team: Alicia Fessler (Primary), Willis Jones, Anna d'Entremont, Dale Hitchcock and Jay Gaillard

Subcontractor: NA

Project Type: Standard

Project Start Date: October 1, 2019
Project End Date: September 30, 2020

The Emergency Response community would greatly benefit from a diagnostic tool capable of determining the charge state of a high-voltage object. The proposed work investigates the detection of gas polarization from dielectrophoretic (DEP) forces as a highly sensitive, static, direct current electric field detector. The polarization, and subsequent alignment of molecules, in the gas phase will have minimal gravity and drag forces, therefore the DEP polarization process is expected to be extremely sensitive at a greater distance from the source and at lower field strengths than existing electric field probes. The DEP assembly and polarization of the gas can be easily measured using Raman spectroscopy. As a deployable tool, we envision a handheld electric field detector with a probe consisting of a sealed cell filled with a Raman-active gas.

FY2020 Objectives

- Develop a Raman system for measuring gas polarization.
- Conduct proof-of-concept of gas polarization in DC fields.

Introduction

The project scope is to investigate the detection of gas polarization from dielectrophoretic (DEP) forces as a high-sensitivity, non-invasive static direct current (DC) electric field detector with target sensitivity significantly higher than commercial devices and high/low voltage differentiation. Particles, molecules, and atoms within a non-uniform DC electrical field gradient are polarized by DEP forces. While DEP forces are relatively small, recent work funded by the Render Safe Technology Integration Program and reported in the open literature, have shown that these forces are sufficient to overcome kinetic (thermal), Brownian, gravity (mass), and drag forces to cause an alignment (i.e., self-assembly) of large molecules (such as carbon nanotubes) at room temperature and at distances of about ten inches with potentials as low as 100 V.[1] Additionally, unlike most other field detection approaches, this approach does not require a change in, or perturbation of, the electric field to produce a signal.

Because gas molecules are much lighter than carbon nanotubes, the gas molecules will have greatly reduced gravity and drag forces. Therefore, the gas molecules should be much more sensitive to the polarization and alignment from the DEP forces. The increased influence of the DEP forces on the gas molecules should allow for polarization to be detected at a greater distance from the source and at lower field strengths than with the carbon nanotubes. The overall process is illustrated for a single component gas in Fig 1 with: a) random orientation of gas molecules, b) polarization and reorientation of gas molecules at ambient temperatures under a DC field, and c) greater alignment at lower temperatures under a DC field.

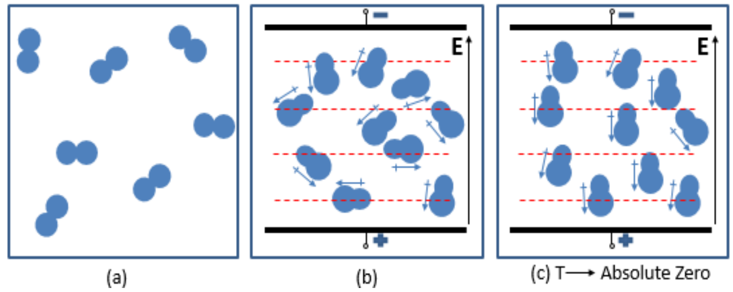

Figure 1: Gas molecules in a gas cell under ambient conditions without (a) and with (b) an applied static electric field; red dashed lines are equipotential lines. As temperature approaches absolute zero, thermal effects are reduced and the gas molecules more uniformly align to the applied electric field (c).

The research will develop a new type of detection method for DC electric fields and set the groundwork for development of a handheld tool which could be used by emergency response workers to detect the charge state of a suspicious object. Several direct and passive methods to determine charge state have been investigated, but without close-proximity (several millimeters) to the high voltage electrical components, the methods lack the sensitivity to unequivocally determine charge state. The DEP forces are expected to have effect on gaseous molecules about 10 inches or more from the electric field source based on measurements of carbon nanotubes.[1] The research will also improve our understanding of the effects of dielectrophoretic forces on gas molecules, as well as quantify the effects (i.e., field strength, source distance, and field geometry) related to the phenomenon being used as a detection method for DC electric fields.

Approach

Raman spectroscopy is an established technique for measuring gas polarization and has been demonstrated as a portable diagnostic tool.[2-3] Previous work in the late 1970s by Aussenegg, et al. showed a change in the polarization of liquid molecules in the presence of a static electric field measured using Raman spectroscopy.[4-5] The proposed work extends the previously investigated principle to gas phase measurements and develop a diagnostic tool to measure depolarization using a Raman-active gas in the presence of an electric field. A deployable tool would consist of a handheld electric-field detector (a sealed gas cell filled with a Raman-active gas) fitted with a thermoelectric-cooled jacket, and a diode laser/detector package to measure gas polarization. In operation, the probe would be moved toward the exterior of an unshielded package of interest, or the interior with a shielded package, and the degree of gas polarization would indicate the charge state of the static DC field. The probe would be designed with a ~1/4”-1/2” diameter and ~3-4” in length (see Fig 2b) to maintain a light-weight tool and allow for measurements within a shielded package.

Results/Discussion

To estimate the strength of the electric field as a function of distance, a 2D axisymmetric model was used with two 1 mm spherical electrodes spaced with the centers 2 mm apart in air and a 1 kV voltage between them. Figure 2 is a plot of the electric field magnitude along the axis of the two-dot pair starting from the outer edge of one of the electrodes. The electric field drops off quickly with only 5% of the value at the electrode surface still present within 5 mm and 10 V/m (from >10^6 V/m) at ~5 cm from the source. The maximum electric field strength in the simulation at the electrode surface between the dots was ~1.7e6 V/m. The dielectric strength of air is ~3e6 V/m, so there is limited scope for increasing the voltage in order to expand the region for large electric fields at a distance from the source.

Therefore, the developed sensor would need to be able to detect 10 V/m or less to increase the distance from the source required for detection.

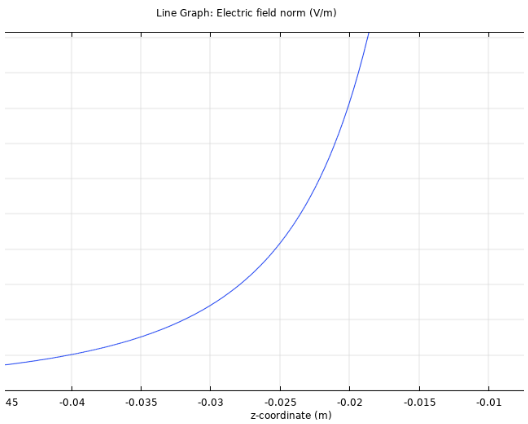

Figure 2: Plot of the electric field strength (V/m) as a function of distance from the source.

The Raman measurement system consists of a Laser Quantum Gem 532 nm laser and a Kaiser f/1.8 Holospec spectrometer. A Raman compatible quartz glass cell filled halfway with liquid cyclohexane was allowed to reach equilibrium within the cell to obtain gaseous cyclohexane in the upper half of the cell. Note: the cell was not pumped down prior to adding the liquid, so some air remained in the cell, as seen in the Figure 3 gas phase spectrum. The Raman cell was placed between two copper plates which were connected to a voltage power supply. Initial testing has only employed a polarized laser for the Raman polarization measurements. Figure 3 shows Raman spectra of liquid and gaseous cyclohexane. The spectrum shows the expected cyclohexane Raman peaks along with some Raman peaks from air constituents. In Figure 4, the parallel and perpendicularly polarized Raman spectra of liquid cyclohexane are shown to demonstrate the capability of measuring polarized Raman with the designed setup. Laser polarized gaseous cyclohexane is shown in Figure 5, and the change in intensity between the two polarizations does not seem identical to the liquid phase. However, literature shows there should be no difference in the depolarization ratio (Intensity of parallel/Intensity of perpendicular) and the observation is likely due to a light collection discrepancy.

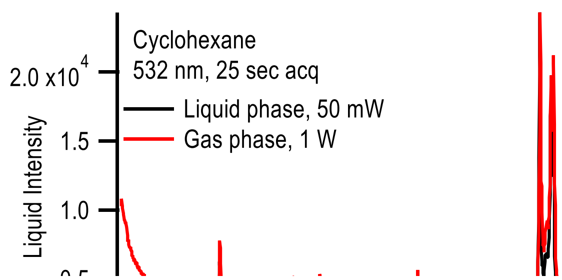

Figure 3: Raman spectra of liquid (black) and gaseous (red) cyclohexane.

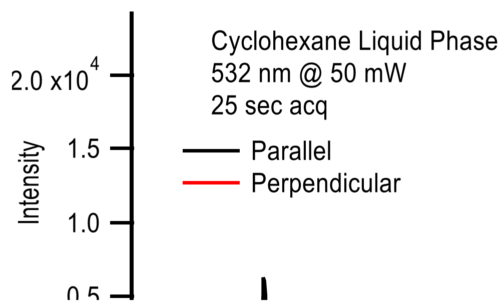

Figure 4: Raman spectra of parallel (black) and perpendicular (red) laser polarized liquid cyclohexane.

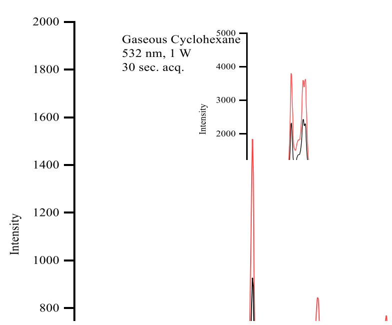

Figure 5: Raman spectra of parallel (black) and perpendicular (red) laser polarized gaseous cyclohexane.

FY2020 Accomplishments

Brief descriptions of accomplishments to date in bullet form. Whenever possible, accomplishments should be stated quantitatively, as in the examples below, and indicate the contribution to meeting the objectives as well as the magnitude of the improvement over past work.

- Designed electric field apparatus to fit gas cell inside field plates.
- Modeling performed to estimate field strength/distance shows the electric field strength falls to 10 V/m at ~5 cm from the high voltage source.
- Raman laser polarized measurements of liquid cyclohexane demonstrates the system is capable of measuring the two polarization states.
- Raman spectra of liquid and gaseous cyclohexane demonstrates system is aligned and ready to measure electric field effects on the Raman spectra.

Future Directions

- Use pulsed electric field at higher voltages and a femtosecond laser to study polarization effects of electric field.
- Cool the gas cell using a thermoelectric cooler to reduce thermal effects.
- Evaluate CO_2 IR spectrum change under electric field influence.
- Add insulating gas to evaluate reduction of electric field induced break down limit.
- Explore other options for detection, such as liquid crystal technology.

FY 2020 Peer-reviewed/Non-peer reviewed Publications

NA

Presentations

NA

References

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Acronyms

List all acronyms used in the report and explain what they stand for.

Intellectual Property

Invention Disclosure: SRS-19-008, Static Electric Field Detection Using Raman Spectroscopy to Measure the Depolarization Ratio of Gas Molecules Influenced by Dielectrophoretic Forces

Total Number of Post-Doctoral Researchers

Willis Jones is an SRNL post-doctoral researcher who contributed to this work in FY20 by performing work onsite.

Total Number of Student Researchers

NA

External Collaborators (Universities, etc.)

Steve Serkiz, Clemson University