



---

**Fourier Transform Infrared Spectroscopy System for the in situ Measurement of Plasma-Catalyst Interactions for Enhanced Reaction Control**

**David Go  
UNIVERSITY OF NOTRE DAME DU LAC**

---

**01/04/2019  
Final Report**

**DISTRIBUTION A: Distribution approved for public release.**

**Air Force Research Laboratory  
AF Office Of Scientific Research (AFOSR)/ RTB1  
Arlington, Virginia 22203  
Air Force Materiel Command**

DISTRIBUTION A: Distribution approved for public release.

**REPORT DOCUMENTATION PAGE**

*Form Approved  
OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Service Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> 12-20-2018		<b>2. REPORT TYPE</b> Final Performance Report		<b>3. DATES COVERED (From - To)</b> 09-30-2017 – 09-29-2018	
<b>4. TITLE AND SUBTITLE</b>  A Fourier Transform Infrared Spectroscopy System for the in situ Measurement of Plasma-Catalyst Interactions for Enhanced Reaction Control				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b> FA9550-17-1-0376	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b>  Go, David B. Hicks, Jason C.				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  University of Notre Dame du Lac Office of Research 940 Grace Hall Notre Dame, IN 46556-5602				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Air Force Office of Scientific Research 875 North Randolph Street, Rm 3112 Arlington, VA 22203				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>  AFOSR	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b>					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b>  The aim of our work is to direct reaction paths using controlled plasma-catalyst interactions in order to develop technologies for chemical synthesis and processing relevant to the U.S. Air Force and Department of Defense. To reach this aim, the goal of this research is to reveal the molecular-level chemistry that occurs at the plasma-catalyst interface. The purpose of this DURIP was to purchase and upgrade a Fourier transform infrared spectroscopy instrument to enable in situ plasma-catalyst studies across a range of temperatures (20-600°C), pressures (10-6-104 torr), and gas compositions. Through this award, we have purchased and installed a Bruker VERTEX 70 Fourier Transform Infrared Spectrometer. We have begun to modify the instrument in order to incorporate a dielectric barrier discharge (DBD) in situ and have also used the instrument for adjacent studies studying the conversion of furfural.					
<b>15. SUBJECT TERMS</b>  gas discharge, plasma, catalysis, FTIR					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>  None	<b>18. NUMBER OF PAGES</b>  6	<b>19a. NAME OF RESPONSIBLE PERSON</b> David B. Go
<b>a. REPORT</b>	<b>b. ABSTRACT</b>	<b>c. THIS PAGE</b>			<b>19b. TELEPHONE NUMBER (Include area code)</b> 574-631-8394

## INSTRUCTIONS FOR COMPLETING SF 298

**1. REPORT DATE.** Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

**2. REPORT TYPE.** State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

**3. DATES COVERED.** Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

**4. TITLE.** Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

**5a. CONTRACT NUMBER.** Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

**5b. GRANT NUMBER.** Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

**5c. PROGRAM ELEMENT NUMBER.** Enter all program element numbers as they appear in the report, e.g. 61101A.

**5d. PROJECT NUMBER.** Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

**5e. TASK NUMBER.** Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

**5f. WORK UNIT NUMBER.** Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

**6. AUTHOR(S).** Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES).** Self-explanatory.

**8. PERFORMING ORGANIZATION REPORT NUMBER.** Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES).** Enter the name and address of the organization(s) financially responsible for and monitoring the work.

**10. SPONSOR/MONITOR'S ACRONYM(S).** Enter, if available, e.g. BRL, ARDEC, NADC.

**11. SPONSOR/MONITOR'S REPORT NUMBER(S).** Enter report number as assigned by the sponsoring/monitoring agency, if available, e.g. BRL-TR-829; -215.

**12. DISTRIBUTION/AVAILABILITY STATEMENT.** Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

**13. SUPPLEMENTARY NOTES.** Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

**14. ABSTRACT.** A brief (approximately 200 words) factual summary of the most significant information.

**15. SUBJECT TERMS.** Key words or phrases identifying major concepts in the report.

**16. SECURITY CLASSIFICATION.** Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

**17. LIMITATION OF ABSTRACT.** This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Service Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.</p>					
1. REPORT DATE (DD-MM-YYYY) 12-20-2018		2. REPORT TYPE Final Performance Report		3. DATES COVERED (From - To) 09-30-2017 – 09-29-2018	
4. TITLE AND SUBTITLE  A Fourier Transform Infrared Spectroscopy System for the in situ Measurement of Plasma-Catalyst Interactions for Enhanced Reaction Control				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER  FA9550-17-1-0376	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  Go, David B. Hicks, Jason C.				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Notre Dame du Lac Office of Research 940 Grace Hall Notre Dame, IN 46556-5602				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Office of Scientific Research 875 North Randolph Street, Rm 3112 Arlington, VA 22203				10. SPONSOR/MONITOR'S ACRONYM(S)  AFOSR	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The aim of our work is to direct reaction paths using controlled plasma-catalyst interactions in order to develop technologies for chemical synthesis and processing relevant to the U.S. Air Force and Department of Defense. To reach this aim, the goal of this research is to reveal the molecular-level chemistry that occurs at the plasma-catalyst interface. The purpose of this DURIP was to purchase and upgrade a Fourier transform infrared spectroscopy instrument to enable in situ plasma-catalyst studies across a range of temperatures (20-600°C), pressures (10 <sup>-6</sup> -10 <sup>4</sup> torr), and gas compositions. Through this award, we have purchased and installed a Bruker VERTEX 70 Fourier Transform Infrared Spectrometer. We have begun to modify the instrument in order to incorporate a dielectric barrier discharge (DBD) <i>in situ</i> and have also used the instrument for adjacent studies studying the conversion of furfural.					
15. SUBJECT TERMS  gas discharge, plasma, catalysis, FTIR					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  None	18. NUMBER OF PAGES  6	19a. NAME OF RESPONSIBLE PERSON David B. Go
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code) 574-631-8394

**A Fourier Transform Infrared Spectroscopy System for the in situ Measurement of Plasma-Catalyst Interactions for Enhanced Reaction Control**

David B. Go  
Rooney Family Associate Professor  
Department of Aerospace and Mechanical Engineering  
Department of Chemical and Biomolecular Engineering

Jason C. Hicks  
Associate Professor  
Department of Chemical and Biomolecular Engineering

University of Notre Dame  
Notre Dame, IN 46556

**AFOSR DURIP Award No. FA9550-17-1-0376**

**Final Report**

**September 30, 2017 – September 29, 2018**

Submitted on: December 20, 2018

**Abstract**

The aim of our work is to direct reaction paths using controlled plasma-catalyst interactions in order to develop technologies for chemical synthesis and processing relevant to the U.S. Air Force and Department of Defense. To reach this aim, the goal of our research is to reveal the molecular-level chemistry that occurs at the plasma-catalyst interface. The purpose of this DURIP was to purchase and upgrade a Fourier transform infrared spectroscopy instrument to enable in situ plasma-catalyst studies across a range of temperatures (20-600°C), pressures ( $10^{-6}$ - $10^4$  torr), and gas compositions. Through this award, we have purchased and installed a Bruker VERTEX 70 Fourier Transform Infrared Spectrometer. We have begun to modify the instrument in order to incorporate a dielectric barrier discharge (DBD) in situ and have also used the instrument for adjacent studies studying the conversion of furfural and aromatic hydrocarbons.

***Journal Articles Submitted***

- Herrera, F.A.; Brown, G.; Barboun, P.; Turan, N.; Mehta, P.; Schneider, W.F.; Hicks, J.C.; Go, D.B., "The impact of transition metal catalysts on macroscopic dielectric barrier discharge (DBD) characteristics in an ammonia synthesis plasma catalysis reactor," *submitted to Journal of Physics D: Applied Physics*
- Bonita, Y.; Jain, V.; Geng, F.; Wilson, W.; Rai, N. and Hicks, J.C., "Direct Synthesis of Furfuryl Alcohol from Furfural: Catalytic Performance of Monometallic and Bimetallic Mo and Ru Phosphides," *submitted to ACS Catalysis* (in revision)
- Bonita, Y.; O'Connell, T.P.; Miller, H.E.; Hicks, J.C., "Revealing the hydrogenation performance of RuMo phosphide for chemoselective reduction of functionalized aromatic hydrocarbons," *submitted to Industrial and Engineering Chemistry Research*

## 1. Project Overview

Catalyst systems are important to many defense-oriented applications such as catalyst-enabled power generation (e.g., fuel cells). Furthermore, many defense-related technologies integrally exploit catalysis in their function, such as the production of essential chemicals and fuels using thermal catalysis. Ultimately, developing new ways to control catalytic processes to exert control over selectivity and energy efficiency will dramatically impact the United States' defense systems – from the scale of individual military vehicles to the entire energy economy of the United States. Plasmas (or gas discharges) offer a unique way to inject energy into a reacting system to promote the reaction and exert control. Furthermore, plasma-catalyst interactions that capitalize on plasma-injected energy offer the opportunity to profoundly reshape the way we approach catalysis. We propose utilizing plasma-enhanced catalytic systems as a novel approach to chemical processing focusing on hydrocarbon gas reforming and nitrogen fixation as model systems.

*The purpose of this DURIP was to purchase a Fourier transform infrared spectroscopy (FTIR) system for in situ and operando plasma catalysis studies to observe and quantify various surface intermediates based on their structure or their surface interaction/configuration.*

## 2. New Instrumentation

Through this DURIP we purchased and installed a Bruker VERTEX 70 Fourier Transform Infrared Spectrometer (FTIR) outfitted with a high resolution, fast scanner (70 spectra/s at  $0.16\text{ cm}^{-1}$ ) as shown in Fig. 1a. We also purchased two different FTIR modules. In order to conduct *in situ* studies of the plasma and catalyst interaction, we will use diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS). To support this, we purchased a Harrick Praying Mantis diffuse reflectance apparatus with a high temperature reaction cell (up to  $900^{\circ}\text{C}$  under vacuum conditions) as shown in Fig. 1b. For quantification, we will use the attenuated total reflection infrared spectroscopy technique (ATR-IR). In this approach, the IR laser impinges upon the bottom of the catalyst bed and the signal strength correlates to the reaction kinetics. In this way, quantitative information, such as reaction rate coefficients, can be extracted from the intensity of the IR signal. For this DURIP, we purchased a Pike GladiATR, diamond-based ATR system with temperature capability up to  $300^{\circ}\text{C}$ . To complement this DURIP grant and to conduct research on plasma-catalyst interactions, we were awarded a regular AFOSR grant (FA9550-18-1-0157), and through a cost-share, purchased a Pfeiffer OmniStar GSD gas analyzer (Fig. 2). This system is used to measure the effluent from the DRIFTS measurements in order to conduct *operando* studies and correlate plasma-catalyst surface interactions with gas conversion.

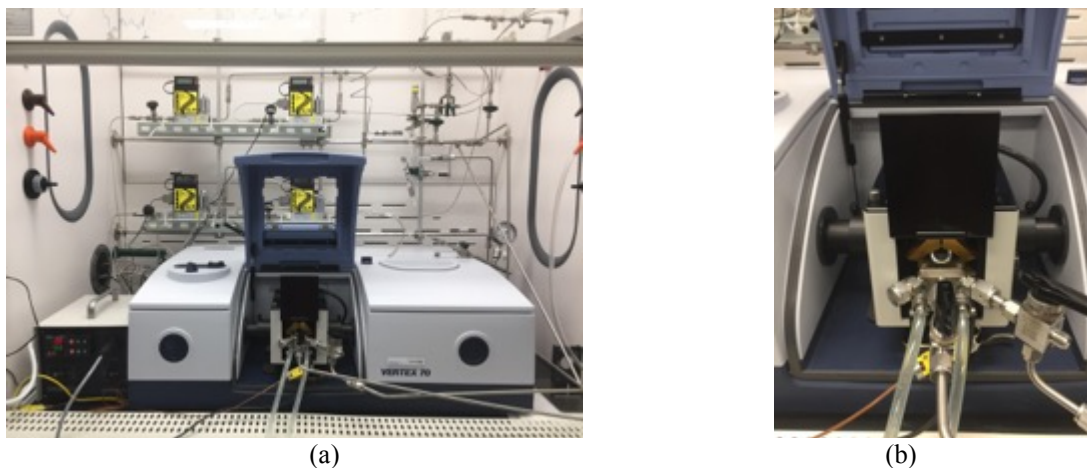


Figure 1 (a) Bruker VERTEX 70 FTIR as-installed in PI Hicks' laboratory fume hood. (b) Closeup of the Harrick Praying Mantis diffuse reflectance apparatus.



Figure 2 Pfeiffer OmniStar GSD gas analyzer as-installed in PI Hicks' laboratory.

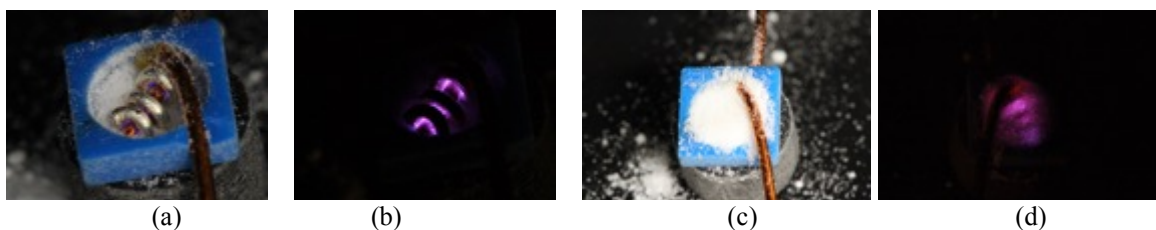
### 3. Preliminary Studies

As noted, we were awarded a regular AFOSR grant (FA9550-18-1-0157) to conduct research on plasma-catalyst interactions. This research has progressed along three thrusts as discussed briefly below.

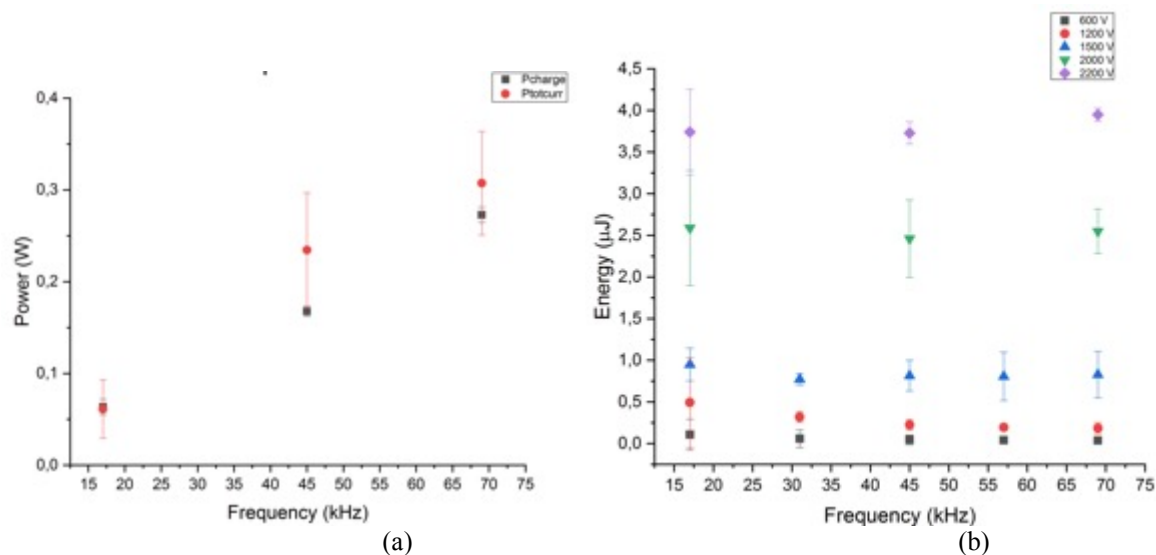
#### 3.1 Development of Plasma Source for FTIR

The DRIFTS cell in the FTIR is very small, with only on the order of several  $\text{mm}^3$  of volume available for incorporating a low-temperature, non-equilibrium plasma. Our primary effort has been to develop a plasma source that that can be directly incorporated into the DRIFTS cell for *in situ* plasma-catalyst studies. This required modifying the DRIFTS cell to allow for wires to feedthrough and to develop a plasma configuration that works within the small available geometry. After exploring several different configurations, we developed a novel configuration that we have termed a helical surface dielectric barrier discharge (hsDBD). This geometry consists of an wire electrode coated in a dielectric (Kapton™) with a second wire wrapped around the outside of the

dielectric in a helix (Fig. 3a). When AC high voltage is applied to the internal wire, a DBD is formed on the outside between the helix and the dielectric, what is known as a surface DBD (often used in plasma-based flow control), as shown in Fig. 3b. This configuration enables us to embed the hsDBD within the small confines of the FTIR cell, even when it contains a catalytic packed bed (Fig. 3c and 3d). To date, we have fully electrically characterized the hsDBD and shown that while the power increases as a function of frequency (Fig. 4a), the energy per cycle does not (Fig. 4b). Rather, the energy per cycle is controlled only by the applied voltage. This gives us two independent parameters to sweep as we study the interaction between plasmas and catalysts.



**Figure 3** Images of helical surface DBD configuration in the cell that contains catalytic material for use in DRIFTS FTIR. Images of system without catalytic material (a) before and (b) after activating plasma. Images of system with catalytic packed bed (c) before and (d) after activating plasma.



**Figure 4** Characterization of helical surface DBD. (a) Power as a function of frequency measured two different ways, using a capacitor (black) and resistor (red). (b) Energy per cycle as a function of frequency for five different applied voltages. The DBD ignited just above 1200 V.

### 3.2 Continuing Studies on DBD Plasma Catalysis Reactor

In our previous AFOSR-sponsored work (FA9550-14-1-0041), we developed a DBD plasma catalysis reactor that we have used to conduct a number of studies on methane dry reforming<sup>1,2</sup> and ammonia synthesis.<sup>3</sup> We have continued this work and although it is not directly related to the FTIR work, will briefly discuss it here.

In our prior work, we found that catalyst performance in a plasma catalysis reactor is not what is expected from thermal catalysis theory; that is, catalyst design for plasma catalysis is different from thermal catalysis.<sup>3</sup> Our results for ammonia synthesis showed that cobalt (Co) produced the highest initial rates compared to ruthenium (Ru), nickel (Ni), platinum (Pt), and iron (Fe). We have

since conducted a thorough quantitative kinetic study of these catalysts to fully characterize their rates and their rate order dependence. We have developed ways to properly account for and normalize the data to isolate the effect of the catalyst independent of the DBD itself in order to properly measure the forward rates for the plasma-catalyst interaction. Among our various findings, we found that the specific energy input (SEI), which is defined as the energy input by the plasma per molecule of gas, is a good descriptor of plasma-based ammonia synthesis, but that the introduction of a catalyst breaks SEI scaling. This interesting result is being prepared for submission to *ACS Sustainable Chemistry & Engineering*.

One of the unknowns about plasma catalysis is the relative impact of the plasma modifying the catalyst activity as opposed to the catalyst modifying the properties of, and thus chemical processes in, the plasma. To assess this, we conducted a comprehensive characterization of the DBD in the plasma catalysis reactor, including both electrical and optical properties. After a thorough statistical analysis, we found that there was no evidence that different catalyst materials (Co, Ni, Fe) affect the plasma differently; that is, different catalysts do not alter the macroscopic properties of the plasma. This result supports the hypothesis that the measured enhancement in catalytic rates is due to the plasma affecting the catalytic process rather than the catalyst affecting gas-phase chemistry. This study has been submitted for publication to the *Journal of Physics: Applied Physics*.

### 3.3 Adjacent Studies on FTIR

While the plasma system is being developed for the FTIR, the FTIR has been also used for a number of adjacent fundamental catalysis studies. Specifically, we studied the use of monometallic and bimetallic molybdenum (Mo) and ruthenium (Ru) phosphides for the synthesis of furfuryl alcohol from furfural. The results showed that MoP, RuP, and Ru<sub>2</sub>P all showed remarkable selectivity to hydrogenate furfural to furfuryl alcohol, while Mo<sub>3</sub>P was inactive. These results have been submitted to *ACS Catalysis*.

We also explored the chemoselective hydrogenation ability of RuMoP using various functionalized aromatic hydrocarbons to provide insight into how the functional groups compete for reduction on the surface of RuMoP. Using molecular hydrogen as the reductant, high selectivity (~99%) to reduction of the substituent is achieved for the hydrogenation of electron withdrawing functionalities such as nitrobenzene, benzaldehyde, and benzophenone with RuMoP to yield aniline, benzyl alcohol, and diphenylmethanol, respectively. Pyridine adsorption was studied via DRIFTS, which provided evidence of surface electron deficient sites (e.g., Lewis acids) that are responsible for targeting the electron rich portion of the substrate. Additional DRIFTS experiments showed features associated with -NO<sub>2</sub> adsorption in nitrobenzene and ring adsorption in anisole, which correlated well with the observed reaction results. These results have been submitted to *Industrial and Engineering Chemistry Research*.

## 4. References

<sup>1</sup> J. Kim, M. S. Abbott, D. B. Go, J. C. Hicks, "Enhancing C-H bond activation of methane via temperature-controlled, catalyst-plasma interactions," *ACS Energy Letters*, vol. 1, pp. 94-99, 2016.

<sup>2</sup> J. Kim, D. B. Go, J. C. Hicks, "Synergistic effects of plasma-catalyst interactions for CH<sub>4</sub> activation," *Physical Chemistry Chemical Physics*, vol. 19, pp. 13010-13021, 2017.

---

<sup>3</sup> P. Mehta, P. Barboun, F. A. Herrera, J. Kim, P. Rumbach, D. B. Go, J. C. Hicks, W. F. Schneider, “Overcoming ammonia synthesis scaling relations with plasma-enabled catalysis,” *Nature Catalysis*, vol. 1, pp. 269–275, 2018.

# AFOSR Deliverables Submission Survey

Response ID:10788 Data

1.

---

**Report Type**

Final Report

---

**Primary Contact Email**

Contact email if there is a problem with the report.

dgo@nd.edu

---

**Primary Contact Phone Number**

Contact phone number if there is a problem with the report

574-631-8394

---

**Organization / Institution name**

University of Notre Dame

---

**Grant/Contract Title**

The full title of the funded effort.

A Fourier Transform Infrared Spectroscopy System for the in situ Measurement of Plasma-Catalyst Interactions for Enhanced Reaction Control

---

**Grant/Contract Number**

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-17-1-0376

---

**Principal Investigator Name**

The full name of the principal investigator on the grant or contract.

David B. Go

---

**Program Officer**

The AFOSR Program Officer currently assigned to the award

Jason Marshall

---

**Reporting Period Start Date**

09/30/2017

---

**Reporting Period End Date**

09/29/2018

---

**Abstract**

The aim of our work is to direct reaction paths using controlled plasma-catalyst interactions in order to develop technologies for chemical synthesis and processing relevant to the U.S. Air Force and Department of Defense. To reach this aim, the goal of this research is to reveal the molecular-level chemistry that occurs at the plasma-catalyst interface. The purpose of this DURIP was to purchase and upgrade a Fourier transform infrared spectroscopy instrument to enable in situ plasma-catalyst studies across a range of temperatures (20-600  $\mu$ C), pressures (10<sup>-6</sup>-10<sup>4</sup> torr), and gas compositions. Through this award, we have purchased and installed a Bruker VERTEX 70 Fourier Transform Infrared Spectrometer. We have begun to modify the instrument in order to incorporate a dielectric barrier discharge (DBD) in situ and have also used the instrument for adjacent

studies studying the conversion of furfural.

### Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

### Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

### SF298 Form

Please attach your SF298 form. A blank SF298 can be found [here](#). Please do not password protect or secure the PDF. The maximum file size for an SF298 is 50MB.

[sf0298-FA9550-17-1-0376-Go.pdf](#)

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF. The maximum file size for the Report Document is 50MB.

[AFOSR\\_FA9550-17-1-0376-Go\\_final\\_report.pdf](#)

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

### Archival Publications (published) during reporting period:

None - three submitted as noted in the report.

### New discoveries, inventions, or patent disclosures:

Do you have any discoveries, inventions, or patent disclosures to report for this period?

No

Please describe and include any notable dates

Do you plan to pursue a claim for personal or organizational intellectual property?

### Changes in research objectives (if any):

N/A

### Change in AFOSR Program Officer, if any:

N/A

### Extensions granted or milestones slipped, if any:

N/A

### AFOSR LRIR Number

### LRIR Title

### Reporting Period

### Laboratory Task Manager

### Program Officer

### Research Objectives

## Technical Summary

---

### Funding Summary by Cost Category (by FY, \$K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

### Report Document

---

#### Report Document - Text Analysis

---

#### Report Document - Text Analysis

---

### Appendix Documents

---

## 2. Thank You

---

### E-mail user

Dec 21, 2018 13:27:56 Success: Email Sent to: dgo@nd.edu

---