

**“Fundamental Mechanisms, Predictive Modeling,
and Novel Aerospace Applications of Plasma Assisted Combustion
-Laminar Flow Reactor and Nanoparticle Studies at Low to
Intermediate Temperatures: “**

Program Overview

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The Ohio State University
Columbus, OH**

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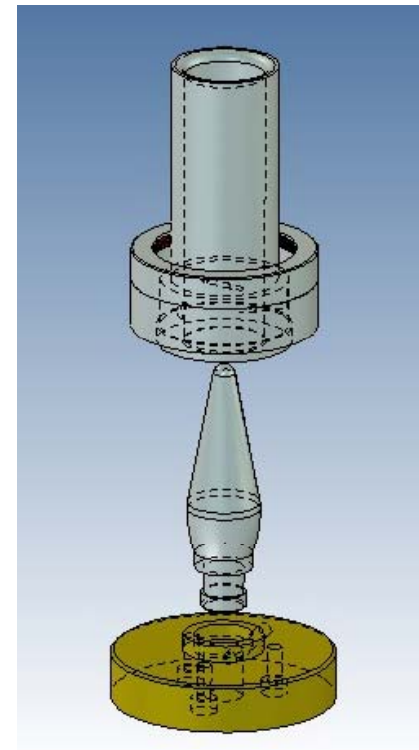
Examples of Combustion enhancement using rotating arc

Advantage of rotating arc

- Non-thermal plasma with relatively high temperature
- 3D expansion of 2D Glid arc
- Reduction of thermal damage
- Increased plasma volume coverage
- Applicable at High pressure



N₂ plasma rotating arc



Rotating arc generator

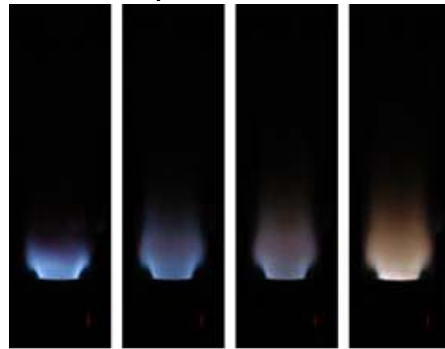
Examples of Combustion enhancement using rotating arc

(Premixed methane/air flame)

Type I

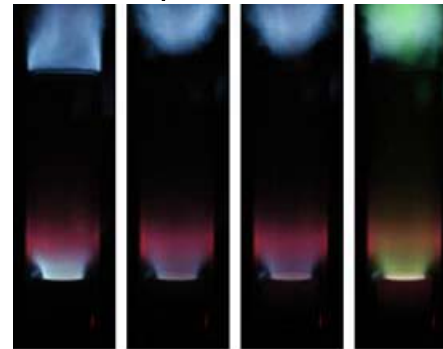


$\phi = 0.57$



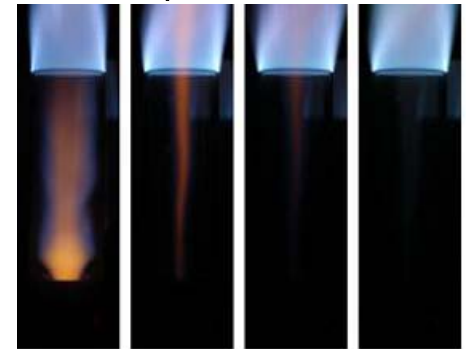
→
Increase of input power

$\phi = 1.27$



→
Increase of input power

$\phi = 1.87$

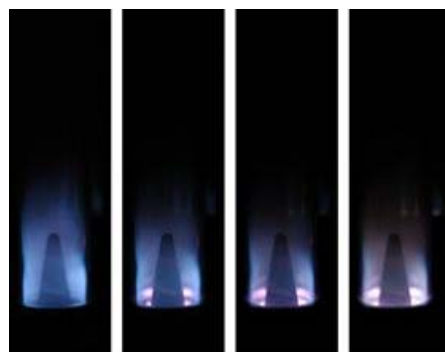


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Increase of input power

Type 2

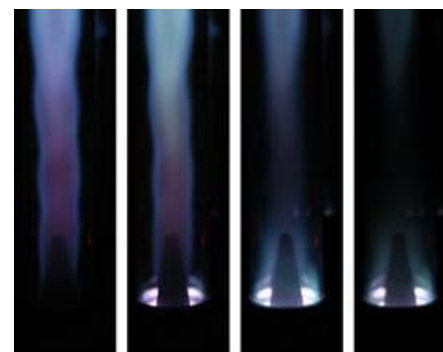


$\phi = 0.77$



→
Increase of input power

$\phi = 1.27$



→
Increase of input power

$\phi = 1.87$



→
Increase of input power

Main tasks

- 1. Reaction Kinetics studies*** with spatially controlled Plasma Discharges
- 2. Effect of nanoparticle*** coupling with plasma enhanced combustion in flow reactors and flames

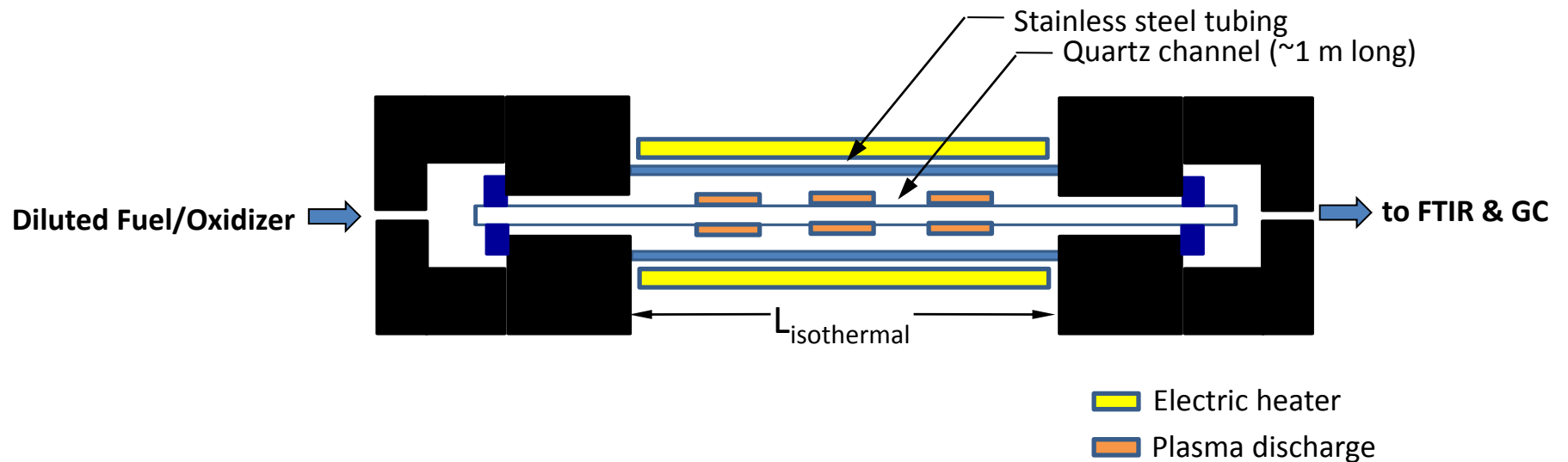
Objectives

- Development and validation of detailed *low-temperature plasma fuel oxidation and ignition mechanisms*, including surrogate fuels
- Development of *reduced plasma chemical fuel oxidation, ignition, and flameholding mechanisms* which can readily be incorporated into predictive multi-dimensional reacting flow codes
- Identification of *specific processes critical to the enhancement of basic combustion phenomena* by nonequilibrium plasmas, in particular processes involving radical and/or excited metastable species.

Reaction Kinetics studies with spatially controlled Plasma Discharges

Approach

- Construct a *laminar flow reactor* for operation between a pressure range of 0.5 and 10 bar and a temperature range of ambient to 1000 K.
- Perform *dilute hydrocarbon oxidation experiments* in excess nitrogen or other diluents to minimize exothermicity of reaction and stretch the reaction spatially over a significant length.
- *Perturb the reaction at different extents of reaction* with a spatially defined plasma discharge.
- Measure *temperature and product species* by sample extraction and GC/FTIR analysis.
- Perform *kinetic modeling of the reaction kinetics* with sensitivity and Green's function analysis ($\partial Y_i(x) / \partial Y_j(x')$).



Schematic drawing of laminar (plug) flow reactor

-Operating temperature: up to 1000 K

-Operating pressure: 0.5 to 10 atm

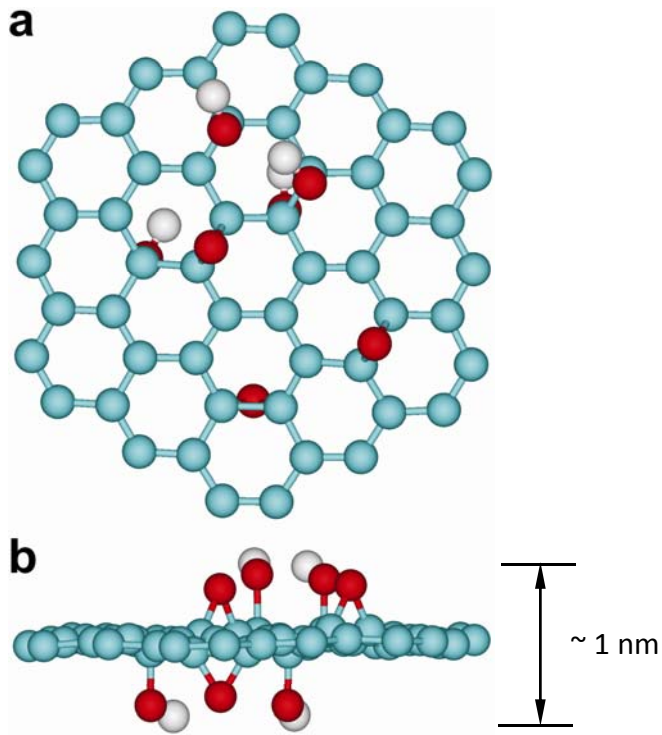
$$\text{Residence time, } \tau = \frac{V}{Q} = \frac{(\pi r^2 L_{isothermal})}{Q_s \left(\frac{T}{273.15} \frac{1}{P} \right)}$$

Effect of nanoparticle coupling with plasma enhanced combustion in flow reactors and flames

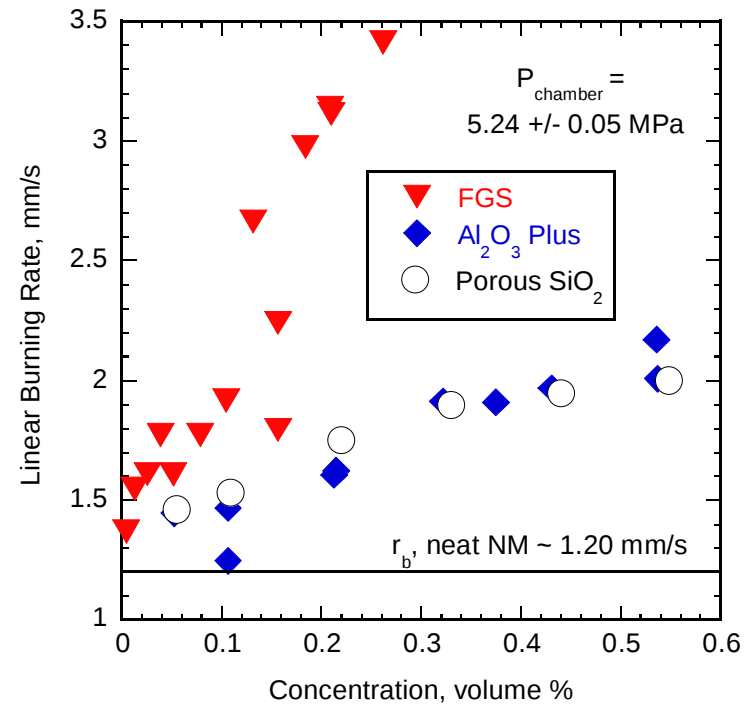
Motivation

- Nano-particles are known to be ionized more easily than molecules and atoms (due to lower ionization potential)
- MD simulation shows that strong ($\sim 10^7$ V/cm) electric field is inherently self-generated in nano aluminum nano-particles at high temperature (~ 1100 K), providing a strong driving force for ion transport
- Nano-particles are chemically and catalytically active in plasma
- Functionalized nano-particles may enhance the effectiveness of plasma

Functionalized graphene sheet colloids enhance fuel combustion!



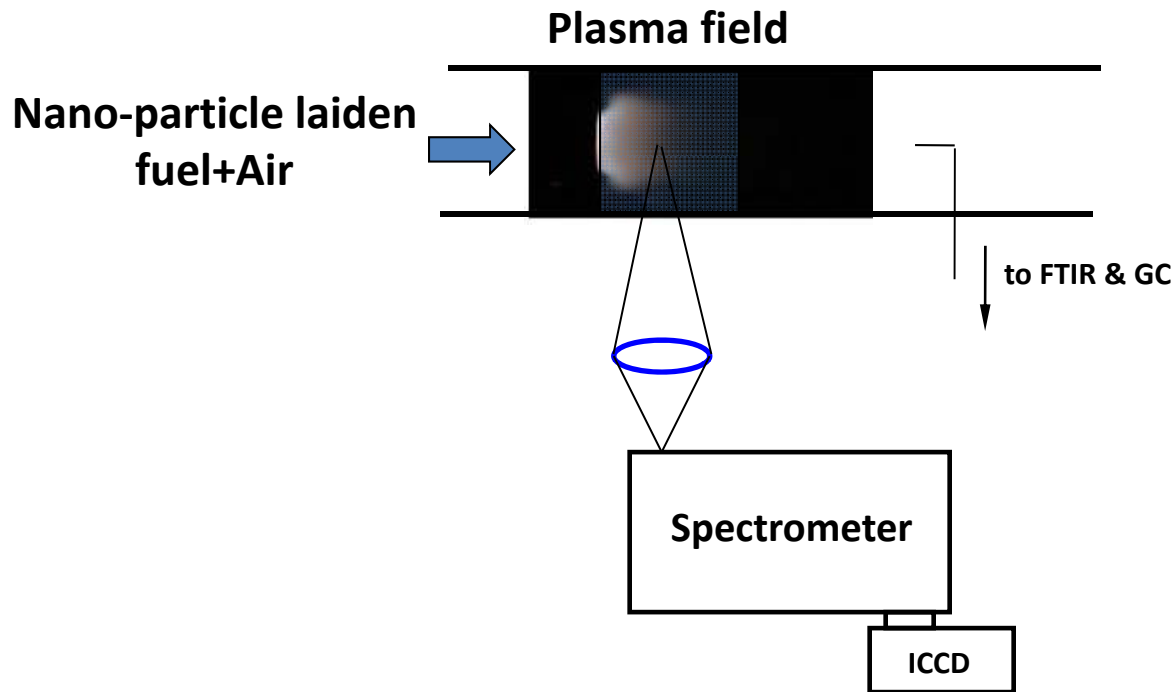
(a) An overhead view and (b) edge-on view of a functionalized graphene sheet



Linear burning rate of nitromethane and catalyst support additive mixtures as a function of volume concentration

Approach

- Studies will be conducted to investigate *the effects of nanoparticles on the plasma characteristics and reaction kinetics*, e.g., lowering the energy for breakdown and provide significant surface area for surface charge and kinetic interactions.
- Particles will be selected that increase the electron density, act as catalysts, and contain significant additional energy content.
- Various *metallic and nonmetallic nanoparticles* (e.g., aluminum, iron, graphene, composite thermites) will be studied.
- The nanoparticles will be entrained into the carrier gas flow through passage of the carrier gas through an electrostatic levitation chamber prior to entering the reactor. For liquids, a nebulizer will be used to create a fine aerosol. Volume fractions of the nanoparticles will be maintained to less than 0.1%.
- Experiments will be conducted *in flow reactors and flames*.



Schematic drawing of a setup laminar flow reactor to investigate the effect of nano-particle coupling with plasma enhanced combustion in flames

Thank you!