Experimental Study of Carbon Dioxide Dissociation in an Atmospheric Pressure Microwave Discharge

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Introduction

Current dependence on fossil fuels to satisfy increasing energy needs has had a nontrivial effect on the overall carbon dioxide (CO_2) content in the atmosphere. The work presented here proposes the use of a plasma system for the destruction of CO_2 to reduce its effects on global warming. A **surface wave discharge sustained by microwaves operating at atmospheric pressure** is experimentally investigated. The total enthalpy of CO_2 decomposition can be represented by

$$CO_2 \rightarrow CO + 1/2 O_2, \quad \Delta H = 2.9 \text{ eV/mol.} \qquad (1)$$

From the above equation we expect to find CO and O_2 as the main products of dissociation in the microwave plasma system.

Visual Changes in Plasma

(A) (B) (C) (D) (E) (F)

Photos (A) – (F) visually demonstrate how the plasma changes from a pure Ar discharge to an Ar discharge with less than 1% CO_2 added.

(A) The plasma is ignited with 15 slm of Ar at 200 W.

(B) The power increases to 400 W and the plasma extends beyond the cylindrical waveguide.

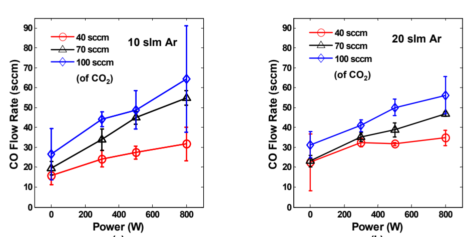
(C) The plasma length continues to grow at 500 W and the **discharge is contracted and filamentary**.

(D) The plasma is ignited with 15 slm of Ar and 70 sccm of CO_2 at 300 W. The color has changed from light purple to light green.

(E) The power is 500 W and the **plasma is noticeably dimmer and more diffuse**.

(F) The discharge becomes stronger as the power is increased to 700 W. Filamentation exists but it is not as dominant as at lower power levels.

Effects of Flow Rate



The input flow rates of Ar and CO_2 were varied to determine if the gas composition had an effect on CO_2 dissociation. The plots above show the production of CO for (a) 10 slm of Ar and (b) 20 slm of Ar. The flow rate of CO_2 was varied from 40, 70 and 100 sccm in both cases. It is clear that **the higher flow rate of CO_2 leads to a higher production of CO**. It is unclear as to how the flow rate of Ar affects CO production.

Questions? Contact Laura Spencer at

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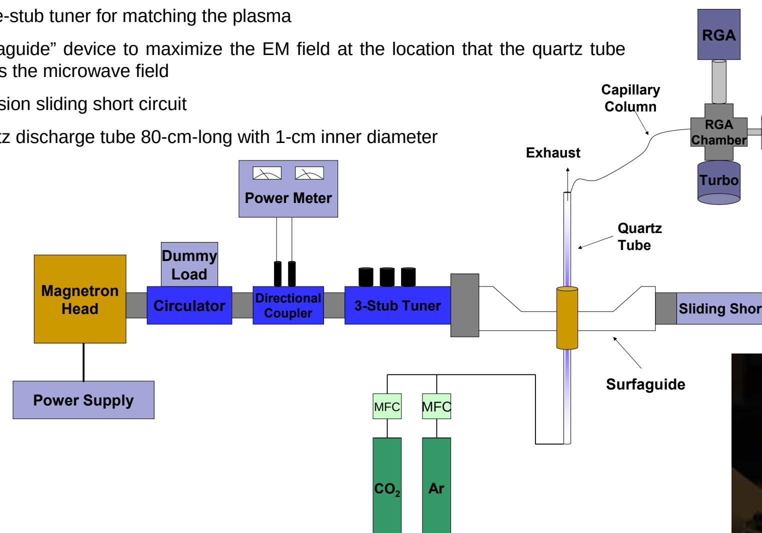
Facilities

All experiments were performed at the Plasmadynamics and Electric Propulsion Laboratory (PEPL) located at the University of Michigan. The microwave system consists of the following:

- 2-kW microwave power supply and magnetron head
- Three-port circulator and dummy load to prevent damage caused by reflected power
- Dual directional coupler and power meter to measure forward/reflected power
- Three-stub tuner for matching the plasma
- "Surfaguide" device to maximize the EM field at the location that the quartz tube crosses the microwave field
- Precision sliding short circuit
- Quartz discharge tube 80-cm-long with 1-cm inner diameter



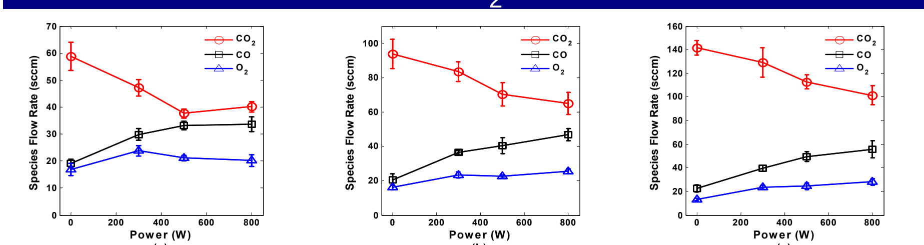
Diagnostics

A Stanford Research Systems RGA100 residual gas analyzer is used in all experiments for species identification. To accommodate the low pressure requirements of the RGA, a separate chamber evacuated by a turbo pump houses the RGA instrument. A capillary tube of fused silica with inner diameter 0.110 mm is attached to a vacuum port on the chamber. The opposite end of the capillary tube is open to atmosphere and is placed inside the discharge tube for gas sampling. The RGA system was calibrated separately for CO_2, CO, and O_2 to determine the effectiveness of detecting each species, and the calibration factor was used to determine the flow rate of species created in the plasma from the following equation.

$$\dot{m}_i = \frac{\dot{m}_{Ar}}{CF}\frac{P_i}{P_{Ar}}$$

Here $\dot{m}_i$ is the plasma produced flow rate of the species in question, $\dot{m}_{Ar}$ is the constant input flow rate of Ar, CF is the calibration factor, P_i is the partial pressure of the target species in question, while P_{Ar} is the partial pressure of Ar.

Evidence of CO_2 Dissociation



The dissociation of CO_2 was studied for various flow rates of CO_2 and Ar, from 40 to 100 sccm and 5 to 20 slm, respectively. The **discharge became more unstable as the addition of CO_2 increased**. Therefore, higher flow rates of CO_2 could not be used in the current configuration. The microwave power was also limited to only 800 W of the total 2 kW capability because of softening and melting of the quartz tube. The plots above show evidence of the dissociation of CO_2 and the creation of CO for the constant flow rate of 15 slm of Ar and (a) 40 sccm of CO_2, (b) 70 sccm of CO_2, and (c) 100 sccm of CO_2. At the lowest input flow rate of CO_2 (a), it appears that a higher percentage of CO_2 is dissociated compared to the higher input flow rates of CO_2 in plots (b) and (c). However in all cases, the output **flow rate of CO_2 decreases with power and the output flow rate of CO increases with power**. From Equation 1, we expect the flow rate of CO to be twice as much as that of O_2 and the above results are consistent with this. Future tests will implement a cooling system to chill the quartz tube so that higher powers and higher flow rates of CO_2 can be tested.