Plasma-assisted CO_2 Recycling: from Earth to Mars

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Overview

Project CREATOR - Plasma-assisted CO_2 Recycling: from Earth to Mars - addresses CO_2 recycling both at atmospheric pressure on Earth for green fuel production, and at low pressure on Mars for making breathable oxygen and fuels. It explores nanosecond pulsed discharges for CO_2 conversion and ion-conducting membranes for product separation. It aims at providing a coupled and integrated description of both volume and surface kinetics in CO_2 plasmas, from conversion to separation, from Earth to Mars.

Research lines:
- Excited states in CO_2 plasmas
- Heterogeneous processes
- Particle transport

Results so far

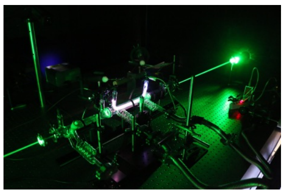
- Open source Kinetic Monte Carlo code for the electron kinetics (*paper submitted*)
- Coupled Monte Carlo description of electron and chemical kinetics (*paper in preparation*)
- Surface kinetics model accounting for plasma effects
- Design of a coupled plasma – conducting membrane system for production and separation of oxygen, optimized for In-situ resource utilization (ISRU) on Mars (*published*)
- Adaptation to solar fuels production on Earth under way

An electrochemical system for ISRU on Mars

In-situ resource utilization
- Mars has a 96% CO_2 atmosphere, with ~2% N_2.
- CO_2 can be decomposed into CO and O
- CO and O_2 can be used for propellants
- O_2 can be used for breathing...
  ... and can be combined with N_2 to produce fertilizers!

Why plasmas
- The local conditions of pressure and temperature are ideal for plasma operation
- Plasmas have fast electrons, that decompose CO_2 upon direct impact
- Additional (non-equilibrium) energy-transfer pathways are available

How it works?
A true synergy:
- Increased efficiency of CO_2 dissociation, by removing oxygen from the plasma and preventing back reactions
- Increased efficiency in the performance of the membrane, due to plasma effects and heat provided by the plasma

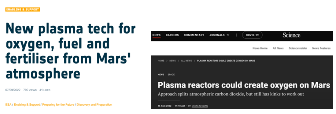


Experimental setup used at the Laboratoire de Physique des Plasmas, Ecole Polytechnique (credits: Olivier Guaitella)

High visibility paper!


Plasmas for *in situ* resource utilization on Mars: Fuels, life support, and agriculture

- Highlights at the *European Space Agency* website and in *Science*



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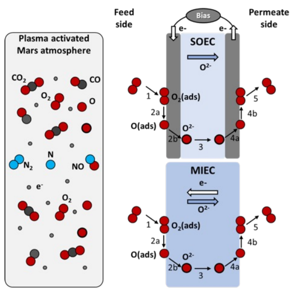


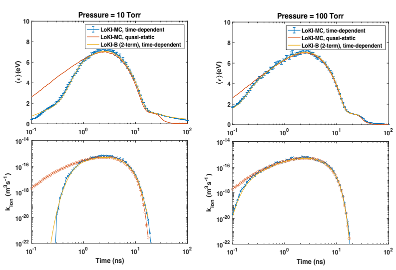
Schematic representation of plasma electrochemical systems

Unified Monte Carlo formulation of plasma chemistry

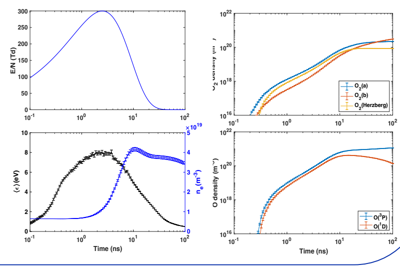
Why Monte Carlo?
- Electrons and heavy-particles treated in the same way
- Accurate kinetics in fast varying E-fields
- Valid for high reduced electric fields
- Powerful tool to investigate nanosecond pulsed discharges

Features
- Straightforward description of the internal degrees of freedom
- Thermal motion of neutrals
- Power balance
- Constant magnetic field at arbitrary angles
- Provides the velocity distribution function
- Thorough validation and benchmarking
- To be released as open source soon!

Time-dependent electron kinetics
- Air mixture
- Fast raising pulse: $\frac{E}{N}(t) = \frac{\hat{E}}{N}\sqrt{\frac{t}{t_{pulse}}}\exp\left(\frac{-t}{t_{pulse}}\right)$, $\frac{\hat{E}}{N} = 700$ Td, $t_{pulse} = 5$ ns



Time-dependent unified kinetics
- Oxygen
- p=10 Torr; T_{gas}=300 K; same E-field pulse



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