Title

Investigation of hydrogen plasma discharge dynamics

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Peer reviewed

Cooperative Research and Development Agreement (CRADA) Final Report

Report Date: Dec 23, 2020

In accordance with Requirements set forth in the terms of the CRADA, this document is the CRADA Final Report, including a list of Subject Inventions. It is to be forwarded to the DOE Office of Scientific and Technical Information upon completion or termination of the CRADA, as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Google and Lawrence Berkeley National Laboratory

CRADA number: FP00008139 (AWD00003285)

CRADA Title: Investigation of hydrogen plasma discharge dynamics

Responsible Technical Contact at Berkeley Lab: Thomas Schenkel

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Sponsoring DOE Program Office(s):
N/A

LBNL Report Number:
tbd

OSTI Number:
[SPO to complete]

Joint Work Statement Funding Table showing DOE funding commitment:

DOE Funding to LBNL	0
Participant Funding to LBNL	$468,000
Participant In-Kind Contribution Value	$32,000
Total of all Contributions	$357,000

Provide a list of publications, conference papers, or other public releases of results, developed under this CRADA:
(Publications must include journal name, volume, issue, Digital Object Identifier)

- C. P. Berlinguette, Y.-M. Chiang, J. N. Munday, T. Schenkel, D. K. Fork, R. Koningstein, M. D. Trevithick, "Revisiting the cold case of cold fusion", Nature 570, 45 (2019); https://doi.org/10.1038/s41586-019-1256-6

- T. Schenkel, A. Persaud, H. Wang, P. A. Seidl, R. MacFadyen, C. Nelson, W. L. Waldron, J.-L. Vay, G. Deblonde, B. Wen, Y.-M. Chiang, B. P. MacLeod, and Q. Ji, "Investigation of light ion fusion reactions with plasma discharges", J. Appl. Phys. 126, 203302 (2019); https://doi.org/10.1063/1.5109445

Provide a detailed list of all subject inventions, to include patent applications, copyrights, and trademarks:
(Patents and patent applications are to include the title and inventor(s) names. When copyright is asserted, the Government license should be included on the cover page of the Final Report)

- "APPARATUS AND METHOD FOR SOURCING FUSION REACTION PRODUCTS", Inventors: Schenkel, Thomas; Koningstein, Ross; Seidl, Peter; Persaud, Arun; Ji, Qing; Fork, David; Trevithick, Matt; Berlinguette, Curtis; Schauer, Phil; MacLeod, Ben; a patent was filed and the serial number assigned is 16/806,760 with a filing date of March 2, 2020.

Executive Summary of CRADA Work:

In this Crada we designed and fabricated plasma discharge devices and operated them with deuterium and hydrogen gases. We studied the dynamics of plasma discharged in the glow discharge regime. We quantified rates of fusion reactions between deuterium atoms and ions that we accelerated from plasma discharges into palladium targets. The results showed enhanced fusion reaction rates in metal hydrides compared to know rates form gas phase reaction, likely due to modifications of the electron screening potentials and associated tunnel barrier probability increases. We modeled this effect and published it in the peer reviewed publications listed above.

Summary of Research Results:
In this Crada we designed, fabricated and operated plasma discharge devices with deuterium and hydrogen gases. We studied the dynamics of plasma discharged in the glow discharge regime. We quantified rates of fusion reactions between deuterium atoms and ions that we accelerated from plasma discharges into palladium targets. The results showed enhanced fusion reaction rates in metal hydrides compared to know rates form gas phase reaction, likely due to modifications of the electron screening potentials and associated tunnel barrier probability increases. We modeled this effect and published it in the peer reviewed publications listed above. We found apparent electron screening potentials of order 1000 keV, much higher than expected from known theory and consistent with earlier studies of dd fusion reactions in metal hydrides. We used neutron detectors to quantify fusion rates, but attempts to also detect charged particles from fusion reactions were not successful due to the plasma background. We modeled the hydrogen plasma discharge to understand ion energy and species distributions. We also modeled the neutron detector data analysis and separation of neutron and gamma signals. We reported this in the JAP article cited above.
Further, we implemented a novel source of deuterium with our plasma discharge. Instead of a common gas supply, we delivered deuterium from an electro-chemical cell to the plasma

through a palladium foil. We filed a joint patent with Google and co-inventors on this invention (see above). Potential use cases are listed in the patent application and include compact supplies of hydrogen isotopes for space missions (where hydrogen is stored in the electro-chemical solution and can be released through the palladium foil into an ion source or plasma chamber or ion thruster or other device. The invention also enables studies of fusion reactions in highly hydrogen loaded palladium, a topic of fundamental interest with potential applications e. g. in neutron generators and potentially relevant for future fusion reactors. Publication of an article on this invention is planned, but was delayed due to Covid.

APPENDIX A (Reference Only)

*This appendix has been developed by DOE to assist DOE Labs in drafting the **Executive Summary** and **Summary of Research Results** sections of the CRADA Final Report.*

Executive Summary of CRADA Work:

Include a discussion of 1) how the research adds to the understanding of the area investigated; 2) the technical -effectiveness of the materials, methods or techniques investigated or demonstrated, and their economic feasibility, if known; and 3) how the project is otherwise of benefit to the public. The discussion should be a minimum of one paragraph and written in terms understandable by an educated layman.

Summary of Research Results:

- *INCLUDE, IF APPLICABLE: "This product contains Protected CRADA Information, which was produced on [DATE] under CRADA No. [##-####] and is not to be further disclosed for a period of [up to and not to exceed] five (5) years from the date it was produced except as expressly provided for in the CRADA."*
- *Summarize project activities for the entire period of performance, including original hypotheses, approaches used, problems encountered, any departure from planned methodology, and an assessment of their impact on the project results. Incorporate technical data, e.g. facts, figures, analyses, and assumptions used during the life of the project to support the technical conclusions of the work. It is acceptable to incorporate the technical data by reference to other publicly available sources, such as a publications or other reports, but not websites. Provide a comparison of the actual accomplishments with the goals and objectives of the project. Where possible, the summary should cover each task listed in the Statement of Work (SOW) and should note any deviations from the project plan, or lack of technical data.*
- *Identify products, potential applications, and technology transfer activities developed under the CRADA, including those completed and anticipated at the time of the report. These include, but are not limited to: 1) networks or collaborations fostered; 2) technologies/techniques/methodologies; 3) other products that reflect the results of the project, such as commercial products, internet sites, data or databases, physical collections,*

audio or video, software, models, educational aid or curricula, and instruments or equipment.

Note: Recommended characteristics of Scientific and Technical Information reports can be found at https://www.osti.gov/stip/attributes