Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

LDRD HQ Highlights Article

1. Title

The Tiny Heater: Creating Heat with Hybrid Nano-Antennas

2. Intro Blurb

Transducing light and magnetic field, heat is selectively generated through nano-antennas.

3. Quotes

"… abundant and inexpensive nano-antennas generate heat efficiently through selective and localized non-contact processes"

4. Graphics

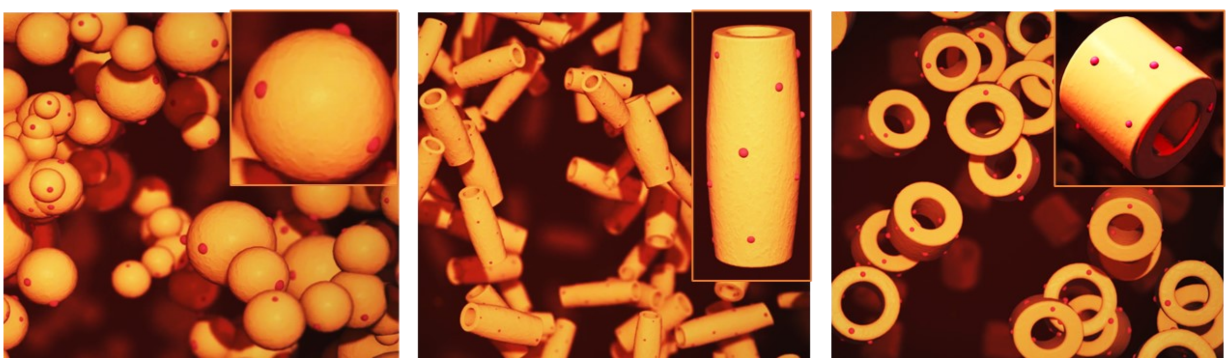


Figure 1. Shape-selective hybrid nano-antenna materials, including spheres, elongated tubes, or equiaxed rings (orange) decorated with nanomaterials (red). The nano-antennas are comprised of various combinations of iron oxide, gold, or palladium materials.

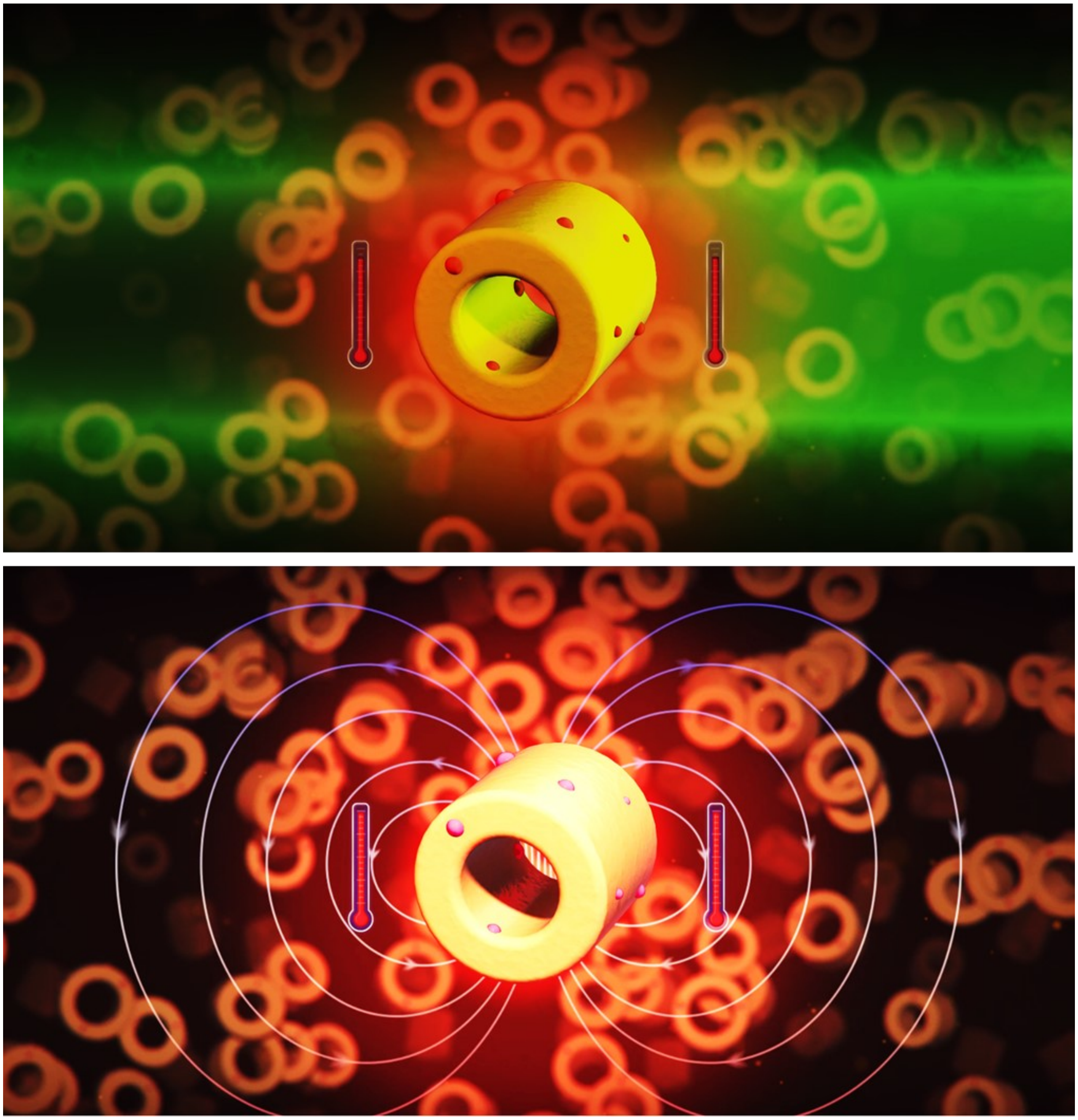


Figure 2. Light (top) and magnetic field (bottom) are used to selectively generate heat using hybrid nano-antennas. Orange color signifies a 'hot' nano-antenna.

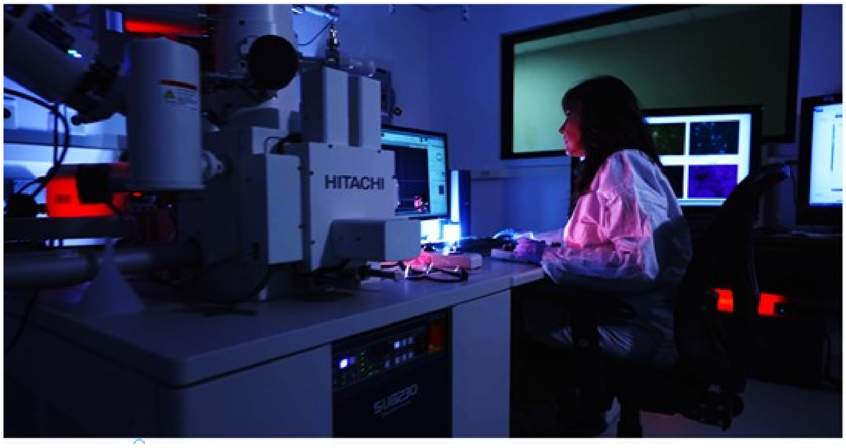
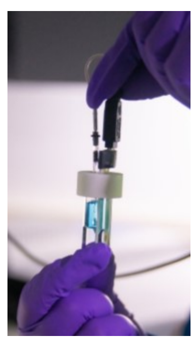
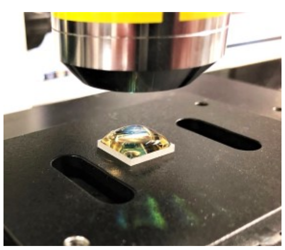


Figure 3. Scanning electron microscope used to characterize nano-antennas.

a. **If you have public links to videos related to the project, please include those links in your submission.**
    - https://www.jove.com/v/53598/multifunctional-hybrid-fe2o3-au-nanoparticles-for-efficient-plasmonic
    - Second one will be included in soon– working with SRNL PR (video was recorded)
    - https://www.youtube.com/watch?v=0LwqpC0eBGQ
    - https://www.youtube.com/watch?v=nekwbESywTY

b. **In addition to project pictures, please submit 1-2 high-res pictures that can be used for other portions of the brochure. These pictures can be science or people related.**





5. **Project (total word count for sections a-f is MAX 800. Less words means larger/more photos. Write at Scientific American level so that a non-technical reader can easily understand the basics of the project.)**

a. **Provide an overview/summary of the project. Describe what it is. Short paragraph of 100 words or less.**

SRNL scientists demonstrate that an electromagnetic field, either as a light or magnetic field, is selectively coupled to shape-selective hybrid nano-antennas for efficient thermal processes. Localized heating occurs extremely fast, reducing the 'wasted' thermal load on the environment. Being non-contact, efficient, and highly selective, the required input energy is greatly diminished. By strategically placing nano-antennas at desired locations, heat can be controlled at the nano-level. The location for nano-antennas, and the subsequent energy deposition, may be fine-tuned through specific chemical, steric, or magnetic interactions. The nano-antennas, composed of combinations of plasmonic, magnetic, and hydride components, are used for controlled release of hydrogen isotopes, chemotherapy drugs, environmental contaminants, enhanced catalytic processes, (bio)imaging and therapeutics.

b. **Why It Matters (sections b, c, and d have a combined MAX 550 words)**
   i. **What does it create? How does it fit in to the big picture for the lab, for DOE, for the field/industry? How does this contribute to the long-term mission of the lab? 129**

Creation of this new class of shape-selective nanomaterial antennas with tailored properties from abundant and inexpensive materials that serve as local "hot-spots" lays the foundation for exciting fundamental scientific discoveries and temperature-controlled applications. These discoveries advance the fields of nanoscience, materials, energy, catalysis, biomedical, and separations by providing innovative, cost-effective, efficient, and environmentally friendly solutions to meet global energy and societal needs.

SRNL provides a continuous opportunity to develop the future Department of Energy (DOE) workforce through the Group for Innovation and Advancements in NanoTechnology Sciences (GIANTS) program. GIANTS' multi-year mentoring and advising program has led to numerous successes and opportunities for postdoctoral researchers and students, including employment prospects at national laboratories, postdoctoral opportunities, graduate school admission, manuscript publications, and conference presentations, including participation in the Nobel Laureate conference.

c. **The Science and Impact**
   i. **What did the team develop/create/test? Provide specific scientific and technical outcomes. What capabilities did this work build? What makes this innovative? Discuss how this research has evolved under LDRD funding. 219**

Materials Discoveries: SRNL researchers discovered that magnetic iron oxide (i.e., rust) performs as well as gold at the nanoscale, allowing for affordable industrial applications. Hybrid nano-antennas can be 'activated' remotely with the "flip of a switch" to generate localized heat on demand. Careful selection of the nano-antennas' size, shape, and composition permits manipulation and control of the thermal process. Further scientific exploration revealed multiple unique applications.

Energy applications: Remote separation and methodical manipulation of 'payloads' in the form of hydrogen isotopes has been successfully demonstrated using hydride-magnetic storage nanomaterials. These innovations expand the DOE's energy security, fusion, and defense missions. Enhanced separation of hydrogen isotopes in liquid media through plasmonic distillation was also achieved. Compared to conventional distillation methods, vapor generation by illuminated plasmonic nanoparticles is promising for more efficient separation processes.
Enhanced catalytic processes: Shape-selective hybrid nano-antennas can photothermally heat aqueous solutions as efficiently as pure gold nanoparticles to transduce light into heat and significantly increase catalytic reaction rates.
Environmental remediation: Efficient and rapid techniques have been demonstrated to enhance detection and extraction of contaminants using iron oxide-gold nanomaterials and remotely remediate environments at a desired location when exposed to light or magnetic field.
Bio-medical applications: Hybrid nanomaterials were explored for targeted chemotherapy drug delivery, nano-thermometer probes, tracking and magnetic resonance imaging platforms.

ii. **Consider the impact of the project on the people involved (e.g., major external awards received).**

Twelve collegiate students and postdoctoral researchers were provided extensive educational training and experience. Scientific recognition and awards include: *Science Daily News*, *PhysOrg* Featured Story, *UGA Featured Story*, *Energy & Fuels* cover magazine, *Inspirational Woman in STEM* Recognition - DOE, and *U.S. C3E Award Finalist in Research* – DOE/MIT/Stanford.

d. What's Next

i. **What are the next steps for this work? What is the PI/team working on and what will they work on in the near future? What will/could this work lead to?**

The pioneering development of nano-antenna materials has enabled numerous applications for focused non-contact generation of heat, which led to the development of 3D/4D printed energy storage materials. These unique nanomaterials have untapped potential in advanced (bio)chemical and catalytic processes, radiation and chemical detectors, advanced manufacturing, environmental stewardship, and biomedical industries (destruction of bacteria or microbial environments, disinfection by remotely raising temperature, and theranostic).

ii. Describe any issued and/or pending patents and licenses.

- *Controlled Release of Hydrogen Gas from Nano Hydrides via Induced Magnetic Field* U.S. Patent
- *Multifunctional Materials for Reversible, High-Capacity Hydrogen Separation and/or Storage* U.S. Patent Application
- *Multifunctional Nanomaterials and Methods of Photothermal Heating and Catalysis,* U.S. Patent
- *Automatic Gas Absorption-Desorption Apparatus and Method,* U.S. Patent Application
- *Radiation Detectors Employing Contemporaneous Detection and Decontamination* U.S. Patent
- *Separation of hydrogen isotopes via plasmonic heating* US Patent Application
- *Targeted Release of Nanoparticle Sequestered Analytes via Plasmonic or Magnetic Fields,* Invention Disclosure
- *Structural Components for UAVs Made of 3D/4D Printable Materials,* U.S. Patent Application

e. Publications (sections e and f have a combined MAX 150 words)

i. Provide links to proposed publications if possible.

1. Hunyadi Murph, S.E. et al *ACS Applied Materials & Interfaces,* 2020, *12*, 9478. https://pubs.acs.org/doi/abs/10.1021/acsami.0c00887
2. Hunyadi Murph, S.E. et al *J. Phys. Chem. C*, 2016, 120, 15162. https://pubs.acs.org/doi/abs/10.1021/acs.jpcc.6b03733
3. Hunyadi Murph, S.E. et al *JOVE*, 2016, 108, e53598. http://www.jove.com/video/53598/multifunctional-hybrid-fe2o3-au-nanoparticles-for-efficient-plasmonic
4. Hunyadi Murph, S.E. et al *Energy & Fuels,* 2021, *35*, 3438. (Journal's cover: https://pubs.acs.org/pbassets/images/_journalCovers/enfuem/enfuem_v035i004-4.jpg?0.6083277028580341)
5. Science Daily News **Modern-day alchemy: Researchers reveal that magnetic 'rust' performs as gold at the nanoscale** https://www.sciencedaily.com/releases/2016/09/160915132444.htm
6. Hunyadi Murph, S.E. et al Anisotropic and Shape-Selective Nanomaterials: Structure-Property Relationships, Springer, 2017, 1-470. https://www.springer.com/gp/book/9783319596617
7. Hunyadi Murph, S.E. et al *Catalysis Today* (Special Issue), 2016, 270, 51. https://www.sciencedirect.com/science/article/pii/S0920586115006847
8. Hunyadi Murph, S.E. et al Metal-Matrix Composites, Springer, 2021, 1-275. https://www.springer.com/gp/book/9783030652487
9. Hunyadi Murph, S.E. et al IEEE International Symposium Antennas and Propagation, 2017, 978-1-5386-3284-0. https://ieeexplore.ieee.org/document/8072494

ii. **Rank in order of priority. If your previous sections are smaller, we may be able to include more.**

f. **Acknowledgements**

i. **Limit extremely large teams to major contributors and/or team leads. 11**

Simona Hunyadi Murph, Henry Sessions, Robert Lascola, postdocs and collegiate students.