Development of techniques to investigate sonoluminescence as a source of energy harvesting

John D. Wrbanek
Gustave C. Fralick
Susan Y. Wrbanek

Instrumentation & Controls
NASA Glenn Research Center, Cleveland, Ohio

Presented at the
43rd Joint Propulsion Conference and Exhibit
Cincinnati, Ohio
July 9, 2007
Outline

• Introduction

• Generation of Sonoluminescence
  – Apparatus
  – Imaging

• Indications of High Temperature
  – Platinum Films
  – Palladium-Chromium Films

• Energy Harvesting
  – Fusion Claims
  – Scintillator Detectors
  – Energy Harvesting Concept

• Summary

“Star in a Jar”
  – W. Moss, LLNL
NASA’s Mission: To pioneer the future in space exploration, scientific discovery, and aeronautics research

“Advance knowledge in the fundamental disciplines of aeronautics, and develop technologies for safer aircraft and higher capacity airspace systems.”
– NASA 2006 Strategic Plan

“Develop the innovative technologies, knowledge, and infrastructures both to explore and support decisions about the destinations for human exploration”
– Vision for Space Exploration
Gas Bubble Expands in Acoustic Wave Pulse

Liquid Pressure Forces Collapse at Pulse Node

Shock Wave of Collapse Focuses to a Point in Microseconds

Energy Released in Imploding Shock Wave as Light

Note: Sonoluminescence is not entirely understood. The origin of the luminosity is the subject of lively debate!
Sonoluminescence in Microgravity

• KC-135 Flight in 1998 by University of Washington
• SBSL promptly brightened 20% and continued brightening under microgravity conditions
• ISS experiment was scheduled for launch April 2005
• Flight hardware under development in 2003
• Experiment cancelled in the redirection of space exploration efforts
NanoStar: Sonoluminescence
Gus Fralick (PI - RIS), John Wrbanek (RIS), Susan Wrbanek (RIO)

Task Summary
- Sonoluminescence: The phenomenon in which acoustic energy is concentrated into collapsing bubbles that emit picosecond pulses of broadband light.
- Calculations indicate that peak temperatures inside the SL bubbles may exceed 12 million K, that peak pressures may reach 100 million atmospheres, could initiate D-D fusion.
- Harnessing the high energy release would lead to the development of revolutionary propulsion and power systems.
- Developing instrumentation and measurement techniques to investigate power generation using sonoluminescence.
- Initially determine whether there is any difference in the emission spectrum of radiation from bubbles in heavy water (D₂O) and light water (H₂O).

Advancing the Existing State of the Art
- The claims and theories are being examined predict a net gain of power resulting from atomic interactions at the high temperatures and pressures present in SL.
- SL-based power generation has been only recently reported in the main-stream academic press (Science, 8 Mar 02).
- The development of measurement techniques to verify and further develop this technology is a necessity.

From a “Star in a Jar”…

...to the Future?
Outline

• Introduction

• **Generation of Sonoluminescence**
  – **Apparatus**
  – **Imaging**

• **Indications of High Temperature**
  – Platinum Films
  – Palladium-Chromium Films

• **Energy Harvesting**
  – Fusion Claims
  – Scintillator Detectors
  – Energy Harvesting Concept

• Summary

“Star in a Jar”
– W. Moss, LLNL
• Ultrasonic transducer induces cavitation in a test cell
• Piezoelectric amplifier drives transducer from signal generator
• Two types of transducer setups
  – Resonating Test Cell
  – “Sonicator” Cell Disruptor in Flask or Beaker
• Photodetectors, Spectrometers, Neutron Detectors can be used
  – Monitor with Lights Out!
Multi-Bubble Sonoluminescence (MBSL) Ring Imaged with Low Lux Video Camera

Compilation of Three Images:
- Lights Off Background
- Lights On Flask
- Lights Off MBSL
Multi-Bubble Sonoluminescence (MBSL) Imaged using Astrophotography Camera

• Image quality allows better placement of instrumentation
• Improved image of MBSL over video camera
  – Enhanced contrast only
MBSL using Sonicator Test Cell

- 100 ml Beaker
- 50 ml Quartz Flask

False Color Images Showing Structure
MBSL in Resonating Test Cell

- 68.76 kHz

- 93.28 kHz
True-Color MBSL in H$_2$O

A Galaxy of “Nano-Stars” in a Jar
Sonoluminescence in Solvents

• Empirical relationships correlate SL brightness with:
  • the liquid’s viscosity,
  • surface tension,
  • inverse of the vapor pressure, or
  • a combination of properties

• Brighter sonoluminescence should be seen in the solvents with higher boiling points (>100°C)

• Glycerin is an attractive solvent for use in sonoluminescence studies
  – Notoriously hydroscopic
  – Stabilizes as the 80% glycerin to 20% water mixture in air
  – Relatively safe and readily available

• Generated cavitation in Glycerin with a Sonicator setup corresponding to bright MBSL
  – Cavitation was particularly localized
  – Provides a promising target for spectroscopy and radiation studies
Outline

• Introduction
• Generation of Sonoluminescence
  – Apparatus
  – Imaging
• Indications of High Temperature
  – Platinum Films
  – Palladium-Chromium Films
• Energy Harvesting
  – Fusion Claims
  – Scintillator Detectors
  – Energy Harvesting Concept
• Summary

“Star in a Jar”
– W. Moss, LLNL
Indications of High Temperature

- Modifications of films can indicate high temperature environments
  - Comparison can reveal temperature differences

- Initial Pt films on alumina exposed to MBSL in H$_2$O and D$_2$O showed little difference
  - Globules in D$_2$O run? Not conclusive

- Pt Film after exposure to MBSL in H$_2$O
- Pt Film after exposure to MBSL in D$_2$O
PdCr Thin Films Over Pt RTD Traces on Alumina

- No Crater Formation seen after exposure to MBSL in H₂O
- Crater Formation seen after exposure to MBSL in D₂O
- Large Grain Failures usually seen in thin films due to CTE mismatches at high temperature (~1000°C)
PdCr Thin Films Over Pt RTD Traces on Alumina

• Large failure areas also seen in PdCr film over Pt exposed to MBSL in D$_2$O
  – PdCr nodules appear on the bottom in failure areas

• Failures not seen in PdCr directly on alumina, or when exposed to MBSL in H$_2$O runs
Outline

• Introduction

• Generation of Sonoluminescence
  – Apparatus
  – Imaging

• Indications of High Temperature
  – Platinum Films
  – Palladium-Chromium Films

• Energy Harvesting
  – Fusion Claims
  – Scintillator Detectors
  – Energy Harvesting Concept

• Summary

“Star in a Jar”
– W. Moss, LLNL
Sonoluminescence: Why do we care?

Burning Coal:
• \( C + O_2 \rightarrow CO_2 \) (4 eV)

Fission:
• \( ^{235}U + n \rightarrow ^{236}U \)
  \( \rightarrow ^{141}Ba + ^{92}Kr + 3n \) (170 MeV)

Fusion Processes:
• \( D + D \rightarrow T \) (1.01 MeV) + p (3.02 MeV)
• \( D + D \rightarrow ^3He \) (0.82 MeV) + n (2.45 MeV)
• \( D + D \rightarrow ^4He \) (73.7 keV) + \( \gamma \) (23.8 MeV)
• \( D + ^3He \rightarrow ^4He \) (3.6 MeV) + p (14.7 MeV)
  – \( D = ^2H, \ T = ^3H; \ D \) available from \( D_2O \), “heavy” water and from deuterated solvents
  – At least 13% more productive per mass of fuel
Lawson Diagram Metric to Track Fusion Development

- Conditions for D-D Fusion:
  - $T \geq \sim 4 \times 10^8$ K
  - $n\tau \geq 10^{16}$ s/cm$^3$ (Lawson Criterion)
- ORNL/Purdue claims that thermonuclear fusion using sonochemistry is possible (“Sonofusion” or “Bubble Fusion”)
  - Results supported by LeTourneau University
  - Discounted by UCLA
- The Lawson Criterion metric suggests that Sonofusion is at the point that Tokamaks were 35 years ago
Thin Film Coated Scintillating Detectors

- Fiber optic-based scintillator detector under development
- Particle emissions react with metal film
  - Results react with the scintillator
- Thin film coatings allow identification of processes that may be occurring

Optical Fiber to PMT
Thin Film Coated Scintillating Detectors

- Prototype detectors fabricated
  - Rhodium for neutron detection
  - Copper as an attenuator,
  - Palladium as a possible catalyst based on thin film experiments
- Relative responses modeled using Monte Carlo program SRIM
- Very sensitive to external light noise
- Leveraging as detectors for Lunar Missions
Energy Harvesting Concept

- Recent results in ceramic thin films suggest this concept is possible
Energy Harvesting Concept

- Initial test of concept to use thin film thermopile for heat flux measurements

- Estimate of power generation:
  \[ 100\mu V/^\circ C \times \Delta T \Rightarrow 200 \text{ mV/junction} \]
  \[ 200 \Omega/\text{junction} \Rightarrow 0.2 \text{ mWatts/junction} \]
  \[ 50\% \text{ efficiency} \Rightarrow 0.1 \text{ mWatts/junction} \]
  \[ 40 \text{ junctions} \Rightarrow 4 \text{ mWatts} \]

- Input electrical power of Sonicator => 350 Watts

- Improvements in thermoelectric materials are needed for energy harvesting to become practical
Summary

• The high temperatures and pressures measured in sonoluminescence have generated claims and theories that predict a net gain of power resulting from atomic interactions.
  – Success has been recently reported in the mainstream academic press, and if practical, could revolutionize aerospace power systems.
• NASA Glenn Research Center (GRC) is developing instrumentation technologies for the support of the mission to pioneer the future in space exploration, scientific discovery, and aeronautics research.
• GRC is leveraging expertise in optical and physical instrumentation research to determine if the potential exists for energy harvesting from sonoluminescence.
• Multibubble sonoluminescence in water and glycerin has been generated at GRC for study.
• The modification of palladium thin films suggests the generation of high temperature from sonoluminescence in heavy water.
• Concepts for in situ radiation detection and energy harvesting are presented.
Acknowledgments

• **Alternate Fuel Foundation Technologies (AFFT) Subproject** of the Low Emissions Alternative Power (LEAP) Project and the **Breakthrough Propulsion Physics (BPP) Project** at the NASA Glenn Research Center (GRC) for sponsoring this work.

• **Nancy Rabel Hall** of the Fluid Physics and Transport Branch at NASA GRC, for providing references and information on sonoluminescence and for reviewing this report.

• **Kenneth Weiland** (retired) and **James Williams** of the R&D Labs Technical Branch at NASA GRC for their optical hardware and electronics support in this effort.

• **Drago Androjna** of Sierra Lobo, Inc. and **José Gonzalez** of Gilcrest Electric as part of the NASA GRC Test Facilities Operation, Maintenance, and Engineering (TFOME) organization at NASA GRC for SEM/EDAX and thin film deposition support respectively.

• **Jonathan Wright** of the University of Florida for this help in reviewing this work.
The Researchers

Gus Fralick*, John Wrbanek* & Susan Wrbanek†
Research Engineers / Physicists
*Thin Film Physical Sensors Instrumentation Research
†Nanophotonics and Optical Micromanipulation Research

Gustave.C.Fralick@nasa.gov
John.D.Wrbanek@nasa.gov
Susan.Y.Wrbanek@nasa.gov
Questions

The Alchemist in Search of the Philosophers Stone, by Joseph Wright (1771)