Low-Cost Efficient and Durable High Temperature Wireless Sensors by Direct Write Additive Manufacturing for Applications in Fossil Energy Systems

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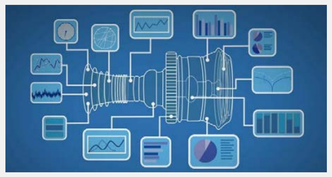
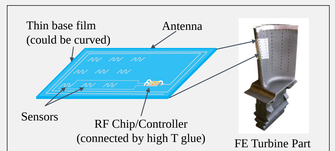
1 Introduction

- Fossil Energy (FE) systems operate at high temperature under harsh conditions
- In-situ monitoring of parameters such as strain and pressure can help improve the combustion efficiency and system safety
- FE components have complex 3-D shapes, making the integration of sensors highly challenging
- Design and green fabrication methods of wireless sensors for in-situ monitoring are required, that
  - Survive in harsh environment
  - Be scalable
  - Be low cost



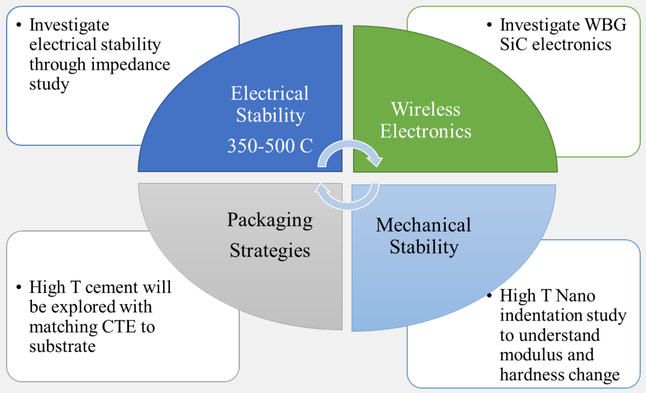
200 sensors across one turbine

Image Courtesy: Dr. Mike Renn, CTO, Optomec.Inc



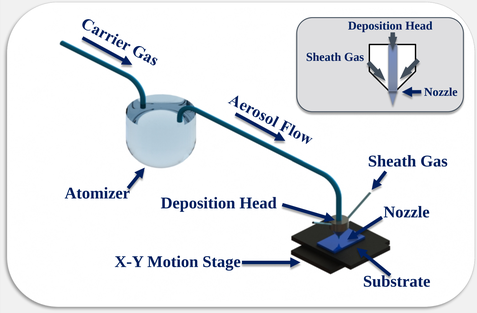
High temperature wireless sensor system

2 Materials and Manufacturing Challenges

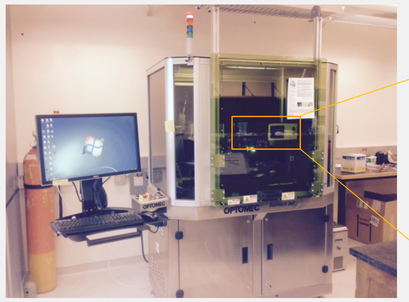


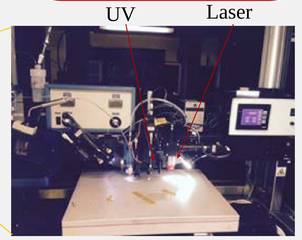
- Electrical and mechanical stability highly important for high temperature applications
- Innovation in packaging strategies required to protect against thermomechanical stresses
- Nano-indentation planned to evaluate the hardness change

3 Aerosol Jet (AJ) 3-D Printer

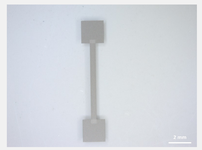


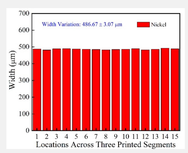
- Microscale printed electronics
- Can print nanoparticle (NP) inks with fine feature sizes to 10 µm
- Ink viscosity ranges from 1-1000 cP
- Variable standoff distance: 1 to 5mm
- Positional accuracy of ± 6 µm
- In situ laser (700mW IR) and UV cuing (1180 mw)



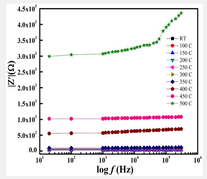


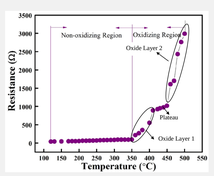
4 Quality and Impedance Behavior of Ni Films

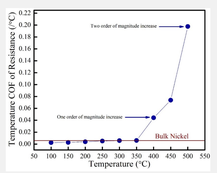




Accurate Printing using Aerosol Jet



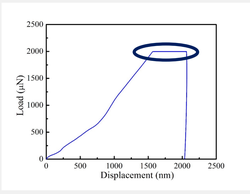


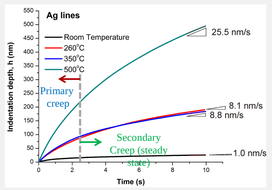


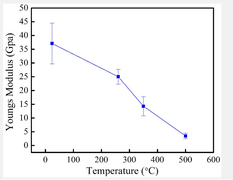
- With the time scale of measurements, Nickel shows high increase in resistance beyond 350 °C
- Ni possibly shows a two stage oxidation behavior, with accelerated oxidation beyond 450 °C
- Microstructural verification using other characterization tools ongoing

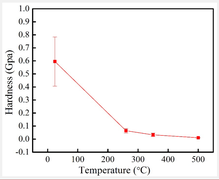
5 Nano-indentation Investigation of Ag Films

High temperature Nano-indenter



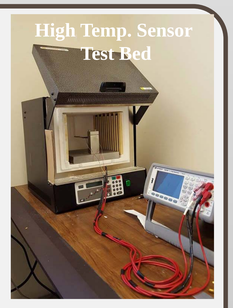






- Hysitron TI900 Triboindenter with heating stage up to 600 ºC (Hysitron, MN)
- Softening of the silver traces observed at high temperature
- Since the sensor action is strain driven, this behavior will result in lower stress in the film, with unknown effect of resistance characteristics
- Typical load-displacement curve exhibits creep behavior
- When the load was held constant for a period of time, the indentation depth (displacement) increases with time.

6 Summary



- AJ printed Ni & Ag nanoparticle films were investigated for high temperature sensor applications using impedance spectroscopy and nanoindentation
- Ni oxidizes heavily beyond about 350 ºC
- Ag films show creep behavior at high temperature
- IS behavior of Ag and evaluation of other materials under investigation
- Printed high temperature antennas and thermomechanical behavior of films will be tested in the future

Acknowledgment

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