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Design and Fabrication of Miniature Engines and Fuel Cells

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A brief review of power generation devices provides insight into advantages and disadvantages of IC engines versus fuel cells. IC engines, especially small ones, exhibit high power density but suffer from limited fuel efficiency. Fuel cells on the other hand perform at relatively high efficiency levels, yet they tend to deliver lower power density when compared to their IC counterparts.

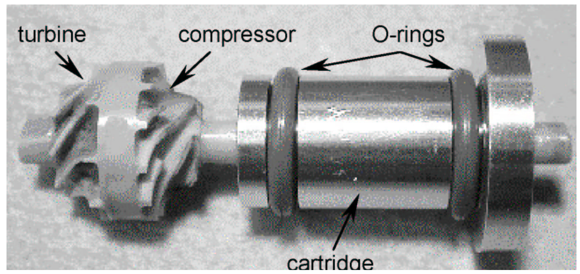

Fig1. Silicon Nitride Turbine compressor group

In this talk we describe progress towards the fabrication of a microscale radial-flow compressor impeller made from silicon nitride (Fig 1) We present manufacturing methods and compressor performance data and discuss them in the context of engine size scaling. Our engine components are made with the help of CNC technology in combination with ceramic gel casting techniques rather than MEMS processing. The present process chain was chosen to achieve necessary accuracy of 3D blade geometry, a significant challenge considering that blade thickness is of the order of a few hundred microns only.

In contrast to the fabrication strategy selected for making miniature engine components we adopt MEMS processing for the creation of fuel cells with micro and nanoscale dimensions. We fabricate both PEMFC (Polymer Electrolyte Membrane Fuel Cell) and SOFC (Solid Oxide Fuel Cell) structures. We observe that, similar to IC engines, downscaled dimensions of fuel cell features may lead to improved power density. However, down scaled dimensions are not necessarily accompanied by diminished fuel efficiency as expected for IC engines. We will discuss fuel cell design variables such as flow channel geometry, catalyst particle size and electrolyte thickness and their influence on fuel cell performance.

We found from CFD models and experimental observations of PEMs that micro channels of decreasing size may lead to improved fuel cell performance. However, flooding may become an issue in channels below a critical size, as water condensation and blocking becomes unavoidable.

It is well known that the performance of fuel cells is closely related to the charge transfer resistance at the triple interface between gas, catalyst, and fuel cell membrane, referred to as Triple Phase Boundary. By varying the size and shape of platinum catalyst particles, we have been able to extract scaling relationships between the geometry of the catalyst structures and their electrochemical properties. The Pt-catalyst features are directly patterned on the surface of polymer electrolyte (Nafion) with the help of a Focused Ion beam probe. Alternatively, we were able to vary the force on the Pt-coated tip of an Atomic Force Microscope to change the length of the triple phase boundary and study its influence on fuel cells behavior.

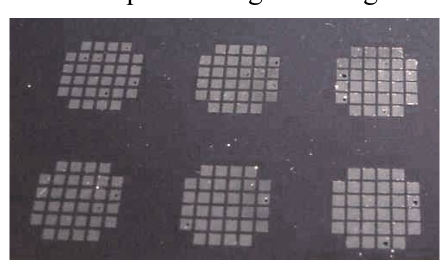
Fig 2. Thin film fuel cell array on Silicon substrate

Finally, we will describe the role of electrolyte membrane thickness in SOFCs. In traditional SOFCs, membrane thickness ranges between 5–20 μm, limiting operational temperatures to the vicinity of 800°C. Reducing the thickness of Yttria stabilized Zirconia electrolyte membranes to 50 nanometers (Fig. 2) promises operational temperatures well below 500°C. This might open applications of miniature SOFC for portable applications in the future.