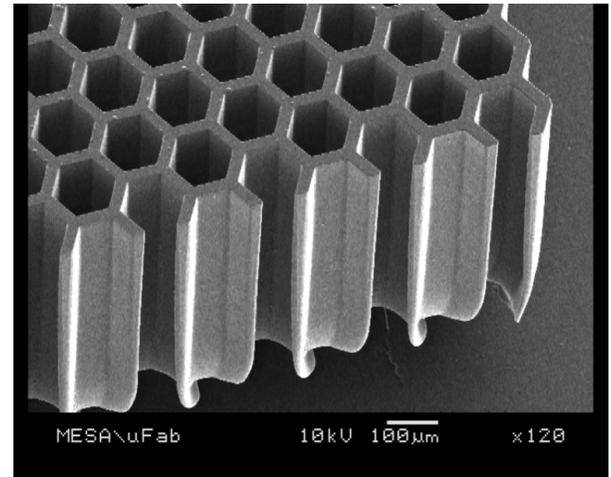
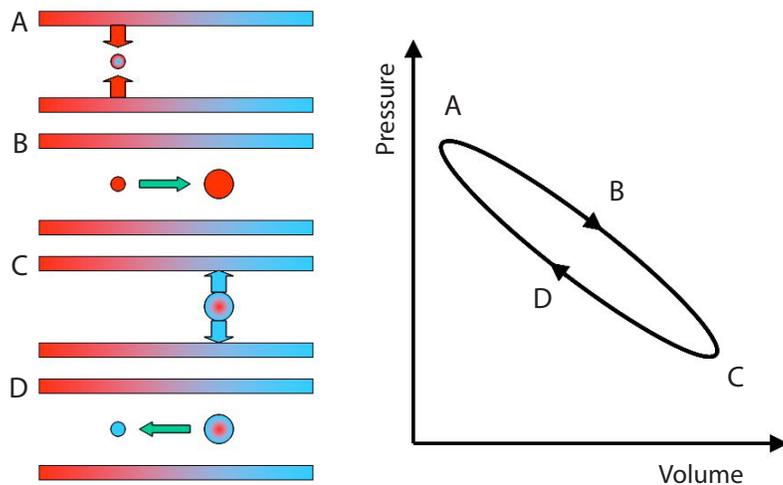




# Microelectronics and Microsystems Power Systems

## Microscale Thermoacoustic Engines



**Figure 1:** The principles of thermoacoustic operation. At (A), heat is added to a parcel of air, at the same time that it is being compressed by a sound wave. At (B), the heated parcel moves from hotter to cooler regions of the stack, expanding as it goes. At (C), the expanded parcel rejects heat to the walls of the stack, but continues to expand. At (D), the parcel moves towards the hot end of the stack, compressing as it goes.

**Figure 2:** Scanning electron micrograph of a microscale thermoacoustic engine stack. The tubes resonate like a pipe organ, launching acoustic energy that can be later converted into electrical power. It is manufactured lithographically from a photosensitive polymer. The walls of the tubes are only 15  $\mu\text{m}$  across, and the stack stands a little over 1 mm tall.

*Heat engines harvest  
electrical power from  
low grade heat that is  
normally lost*

For more information:

**Technical Contact:**

Chris Apblett  
(505)-272-7125  
caapble@sandia.gov

**Science Matters Contact:**

Alan Burns  
505-844-9642  
aburns@sandia.gov

**F**or every joule of energy that is converted into useful work, several joules of energy are lost through the generation of heat. Since much of this heat is localized and in close proximity to a much cooler environment, temperature gradients are usually present when work is performed. In order to reclaim some of this wasted energy, efforts are being made to develop "heat engines," mechanical devices that extract work from heat gradients. By miniaturizing robust heat engines, Sandia hopes to use them to power small devices.

Large scale heat engines typically work by letting a working fluid (either a liquid or a gas) absorb and reject heat in a specific order such that the pressure change that the working fluid experiences acts upon a piston or other mechanical device. However, this technology is difficult at the microscale due to the challenges of producing leak-free miniature sliding seals and friction-free moving parts.

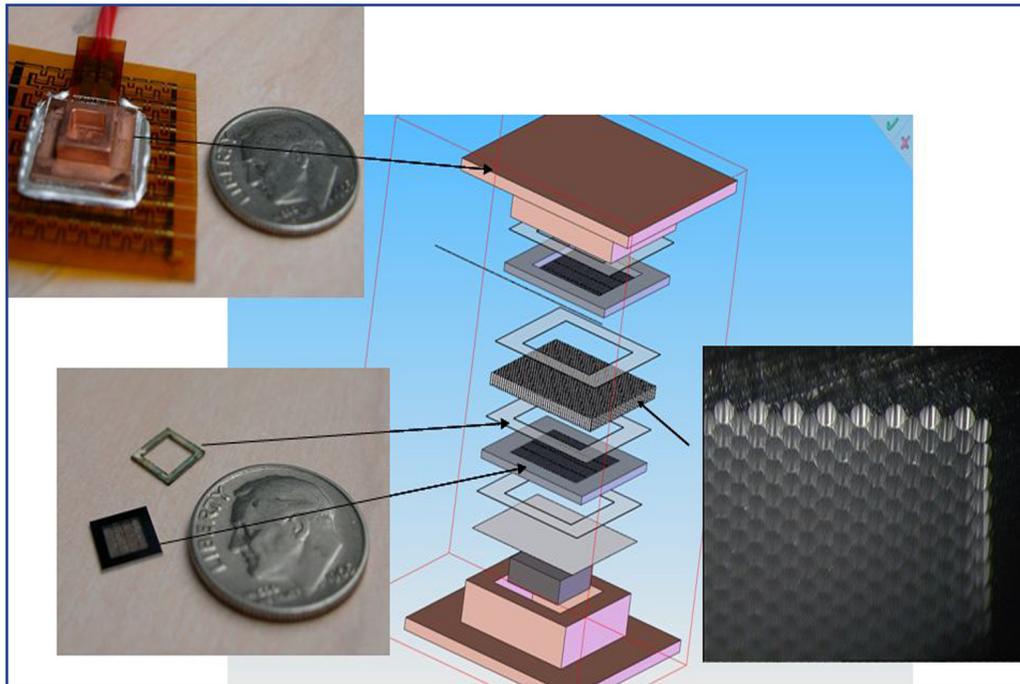
Instead, in conjunction with Los Alamos National Laboratory (LANL), Sandia has developed a miniaturized thermoacoustic engine (Fig. 1), where the heat gradient sets up an acoustic resonance like the sound from a pipe organ. These engines thus have tuned pipes to launch sound waves from a collection of precisely sized tubes. By making the tubes just the right size, and having tuned volumes above and below them, the pipes produce an energetic sound wave that drives a membrane into resonance. Mechanical energy in that vibrating membrane can then be converted into electrical power.

The critical determinant of thermoacoustic engine efficiency is the accurate production of groupings of tuned pipes, known as the "engine stack." Using its microfabrication facilities, Sandia has recently demonstrated the manufacture of an efficient microscale engine stack (Fig. 2), as well as several other critical components of a small scale

thermoacoustic engine. A fully assembled engine, with micro-scale crystalline silicon heat exchangers that help transfer the heat uniformly across the hot and cold sides of the engine stack, is slightly less than a quarter of an inch tall (Fig. 3).

From simulations of the performance, the Sandia-LANL team predicts that a heat gradient as little as 10 °C, and heat fluxes as low as 20 mW/cm<sup>2</sup>, could result in 10-100 μW/cm<sup>2</sup> of mechanical power. Significant challenges remain prior to producing a working device, such as filling the stack with the correct working fluid, and creating a membrane that can

integrally convert mechanical into electrical power. Small engines like these could make use of heat in car engines to power small sensor systems or other electronics. Other examples include using sun-warmed rocks for border security sensors, or continuously powering pressure sensors in power generating turbines, giving early warning of failures or overpressures. Whatever the application, the ability for miniature engines to scavenge otherwise wasted energy and turn it back to useful power is sure to be welcome.



**Figure 3:** Assembly schematic of a microscale thermoacoustic engine, along with some of the subcomponents. The upper left figure shows a heat concentrator and heat flux monitor. The lower left shows a close up of a silicon micromachined heat exchanger and a gasket. The lower right shows an earlier version of the stack, made by using synchrotron radiation to pattern a polymer.