Vacuum Microsystems for Energy Conversion and other Applications

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For the past three decades, the Transducers Conferences have reported advances in the use of *solid-state* technology for fabricating sensors, actuators, and microsystems. For many applications, micromechanical structures must operate in a hermetically sealed, low-pressure ambient. This need motivated the development of low-cost, wafer-scale vacuum encapsulation processes, which have been essential in the commercialization of silicon rate gyroscopes and microresonators. This paper identifies a promising new direction for microsystems technology, in which *vacuum* is more than simply the ambient surrounding a microstructure, but rather is a critical element in device operation. Two motivating applications will be explored: thermionic energy conversion and micro-resonant cavity devices for THz electronics.

Thermionic emission from a heated cathode, followed by collection of the electrons on an anode at a lower temperature, is the operating principal of a thermionic energy converter. A 6 kW thermionic converter, fabricated using precision machining and vacuum-tube technology, was flown in the 1980s by the Soviet space program. Thermionic converters can be adapted to a wafer-stack format, in which advances in materials, micromachining, and vacuum encapsulation processes can be used to enhance performance and reduce fabrication costs. Potential commercial applications include topping cycles in small-scale co-generation. Recently, a new conversion concept has been demonstrated in which a semiconductor photocathode replaces the conventional metal cathode. This photon-enhanced thermionic energy (PETE) converter harvests photon energies above the bandgap, as well as broad-spectrum radiation through heating of the photocathode; it is attractive as the high-temperature topping cycle for solar-thermal power stations. Micro- and nano-structured, high-temperature materials and micromachining processes are also essential to fabricating wafer-scale, cost-effective PETE converters.

A second application-driver for vacuum microsystems is the development of efficient sources and amplifiers for frequencies in the THz range. Conventional three-terminal solid-state devices suffer from low efficiency as they are scaled for operation above 100 GHz, due to reduced breakdown voltages and impedance matching challenges. In vacuum, electrons can be confined in a potential well and undergo long-term oscillations, thereby allowing power to be coupled over several cycles. This concept was first exploited by resonant-cavity power tubes, which achieved GHz-frequency operation before 1930. A modified Barkhausen-Kurz (BK) oscillator for THz frequencies can be fabricated using deep reactive-ion etching processes and wafer bonding, with a silicon carbide thermionic-injection filament formed on the sidewall of the cavity. Progress toward a micro-BK oscillator will be described, as well as approaches to coupling power to and from the cavity. Finally, vacuum microsystems technology will progress more rapidly, due to the ability to embed microsensors and actuators for active monitoring and control of device operation.