Keynote Lecture

ON MICROSCALE ENERGY CONVERSION AND MECHANICAL POWER GENERATION THROUGH EXPLOSIVE VAPORIZATION FROM MICROHEATERS

By

Dimos Poulikakos
Institute of Energy Technology, Laboratory of
Thermodynamics in Emerging Technologies,
Swiss Federal Institute of Technology, ETH Center
CH 8092 Zurich, Switzerland
Tel:: ++41 1 632 2738, Fax: ++41 1 632 1176
E Mail: dimos.poulikakos@ethz.ch

ABSTRACT

The exponential growth of microelectrome-chanical systems (MEMS) in a variety of technological applications has provided impetus for the development of energy conversion methods directly related to the operation of these systems. It is often the case that this conversion should produce at the end mechanical work, as needed, for example, for the operation of micropumps, microactuators, microswitches and micro-valves,) all already popular MEMS applications.

In this lecture, the employment of microheaters to induce explosive vaporization of a liquid and through this vaporization to achieve direct conversion from electrical to thermal and to mechanical energy, is discussed with the help of two microheater geometries: a rectangular film heater of the kind widely used in bubble jet printers and an ultrathin platinum wire. The measurement results presented are based on two recent papers by Poulikakos and co-workers [1,2].

The obvious advantage of the above mentioned energy conversion process lies in its simplicity: No complicated (micro-) machinery is involved, as a matter of fact, no “moving parts” are needed at all for the generation of mechanical work. A thermodynamic evaluation on the other hand, clearly reveals that the first law efficiency is extremely low. Since to date the actual manufacturing of MEMS devices has taken precedence over thermodynamic optimization of such devices, energy efficiency issues are hardly considered. With the growth in the utilization of MEMS devices, energy issues are bound to take on an increasingly important if not dominant

role. The micro-heater paradigms considered in this lecture, underline the importance of the thorough understanding of the relevant thermofluidic mechanisms, as well as the great need for efficiency improvements (in an order of magnitude sense). In all, energy conversion in microscale systems presents itself as an exciting new research field for the energy engineer.

In transitioning from the macroscopic to the microscopic dimensions of microdevices, electrostatic and pneumatic or pressure forces are becoming of increasing importance to the functionality of such devices. Pressure driven microdevices can produce 10^3 times higher force per unit volume than electrostatic devices. If operated at high cycle frequencies, pneumatic devices are expected to provide power per unit volume ratios between 10^2 and 10^3 times greater than their electrostatic counterparts. It is estimated that the peak pressure of a vapor explosion on microscopic heaters that can be manufactured today can reach many atmospheres. Successful extraction of the work from the high pressure pulses generated by the microscopic vapor explosions could revolutionize the operation of microscale systems

Results of the explosive vaporization of water from a metastable state investigated at the microscale level using a rectangular microheater (100μm x 110μm) and a short (1 mm in length) and ultrathin (10 microns in diameter) Pt wire will be presented [1,2]. It was possible to obtain novel visualizations and, simultaneously, pressure and temperature measurements in the vapor microregion, thus accomplishing a step forward in understanding the complex behavior of explosive vapor nucleation, despite the prohibitingly short time and length scales of the phenomena. The measurements of acoustic pressure combined with a simple theory involving the Rayleigh-Plesset equation, allows the calculation of the vapor pressure. With the vapor pressure known, it is possible to estimate the mechanical work that can be extracted from the vapor explosion, as well as the corresponding efficiency.

The second part of the lecture focuses on nanoscale level phenomena of explosive vapor nucleation, directly related to the applications mentioned earlier. Molecular dynamics simulations of the vaporization phenomenon of an ultra-thin layer (2 nm) of liquid argon on a Platinum surface are discussed [6]. The simulations start from a

molecular system of three phases (liquid Argon, solid Platinum and Argon vapor) at equilibrium at 110 K. The Platinum wall is then suddenly heated to a higher temperature (a moderately higher temperature of 150 K and a much higher temperature of 300 K were investigated). Features of the simulation model include a fast algorithm based on a tree data structure and a constant temperature solid wall model based on a 3-D Langevin equation [6]. The entire vaporization process was successfully simulated. The results reveal trends that agree with our knowledge of vaporization of a similar macroscopic system. For example, for the high surface temperature the vaporization process is reminiscent of the Leidenfrost phenomenon and after the formation of a vapor region between the surface and the liquid mass, the latter deforms and tends to approximately acquire a spherical “droplet” shape, as one would have expected from macroscopic considerations. Contrary to this, a gradual evaporation process occurs at moderate wall temperatures. After complete evaporation and upon reduction of the wall temperature, condensation takes place leading to reconstruction of the initial liquid layer.

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