A micromachined picocalorimeter sensor for liquid samples with application to chemical reactions and biochemistry

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Abstract

Calorimetry has long been used to probe the physical state of a system by measuring the heat exchanged with the environment as a result of chemical reactions or phase transitions. Application of calorimetry to micro-scale biological samples, however, has been hampered by insufficient sensitivity and the difficulty of handling liquid samples at this scale. We describe a micromachined calorimeter sensor that is capable of resolving picowatt levels of power. The sensor consists of a set of ultra-low-noise thermopiles on a thin silicon nitride membrane that allow direct differential temperature measurements between a sample and four coplanar references, which significantly reduces thermal drift. The partial pressure of water in the ambient around the sample is maintained at saturation level using a small hydrogel-lined enclosure. Prior to measurement, the hydrogel is equilibrated with water at the same temperature as the sample so that it maintains a water partial pressure inside the chamber close to the water vapor pressure at that temperature, thus reducing the driving force for evaporation without direct contact with the sample. The materials used in the sensor and its geometry are optimized to minimize the noise equivalent power generated by the sensor in response to the temperature field that develops around a typical sample. We have characterized the experimental response of the sensor as a function of thermopile dimensions and sample volume. We demonstrate the capability of the sensor by probing the energetics of an active microtubule gel that is driven by molecular motors and that displays emergent large-scale flows. Surprisingly, we find that only a minute fraction of the system's total energy dissipation stems from these emergent flows and that this cannot be explained by a motor subpopulation that hydrolyzes ATP, but does not contribute to the emergent flows. We have developed a chemical kinetics model that quantitatively captures how the total dissipation varies with ATP and microtubule concentrations. Finally, we offer an estimate of the energy losses across scales.