Molecular Electronic Transducers Based Micro-Seismometers for Planetary Exploration

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Introduction: Understanding the structure, dynamics, and evolution of comets, asteroids, and planets requires a detailed imaging of their interiors. Constraints on interior structure provide unique information regarding the environment from which planets condensed and subsequently differentiated, and in general are the primary ways we build an improved understanding of the formation, evolution, and current state of these bodies. To obtain a first-order constraint on the interior structure of planets and asteroids, the most typical approach is to measure its pole orientation and libration, moment of inertia, gravitational field, and topography to develop models of its interior. However, demonstrated by myriad terrestrial investigations, seismic methods are the only ones with the potential for high resolution mapping of internal heterogeneities and layering from the surface to the center.

Efforts to develop planetary seismometers using mass-spring systems have yielded modern generation instrumentation. Both very broadband (~10 Hz to 0.01 Hz response) and short period (1 Hz to 10s of Hz response) seismometers have been in flight-development for years (e.g., the Japanese Lunar missions). However, sensitive instruments with extended dynamic range and broad bandwidth have been, until now, high power, high mass, and high cost, and are currently available only for lander-based missions, such as the InSIGHT mission. At present, a robust, low power, low mass, small form factor, and relatively low cost broadband seismometer that can be deployed flexibly across a broad range is still under pursuing by researchers[1-3].

The instrument concept introduced here --- Molecular Electronic Transducers (MET) based seismometers --- has all above mentioned characteristics demanded for next generation of planetary seismometers, with the critical advantage of being orientation independent, that is to say the package can be emplaced in any orientation and it will function correctly. The design is also characterized by an extreme high shock tolerance, further enhancing its potential, and has the capability to provide a viable solution for future missions across a broad spectrum of deployment vehicles (e.g., lander, rover, and penetrator) and mission goals.

The core component in the MET seismometer is the molecular electronic sensing cell[4], shown in Fig. 1. Two pairs of electrodes configured as anode-cathode-cathode-anode (ACCA), separated by dielectric spacers, span the width of channels filled with an electrolyte containing iodide ions. Holes through the electrodes and dielectric spacers allow fluid to flow

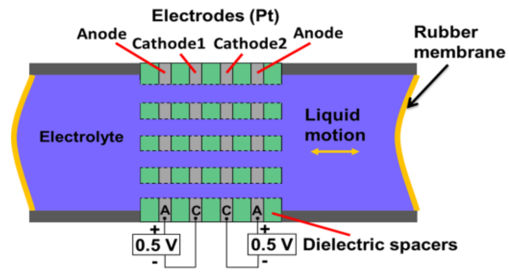

Fig.1 Schematic for MET sensing cell

through the channels. The ends of the channel are capped by high-flexibility diaphragms, allowing the fluid to behave inertially. Each anode-cathode pair in the cell is actually an electrochemical cell. When two electrode pairs are equally biased with electrical voltage, reversible chemical reactions transfer charges between the anode and cathode via ions in the electrolyte. Therefore, electrical current is established within the pair. Without fluid motion, diffusion is the only mechanism to transport the ions in solution. A symmetric pattern of ion concentration develops, resulting in a symmetric current in the ACCA electrode pairs. In the presence of an external ground acceleration, the inertial driving force then is applied to the liquid electrolyte, which produces the movement of electrolyte, resulting in an asymmetry in the electrical currents. By reading out the current differential, the ground motion is determined.

The concept of MET seismic sensors has been explored for several decade and commercialized by MET Tech, Inc. (Jersey City, NJ) and R-Sensors (Russia) recently. However, the reproducibility and performance are highly limited due to manufacture methods. A major advance enabled from our research at ASU is the development of the first miniature MET sensing element, fabricated using Micro Electro Mechanical Systems (MEMS) technology to enhance the performance and the operation capability in the harsh environments for planetary exploration applications.

Instrument Development and Verification:

Noise floor and bandwidth: We have peer-tested none-MEMS MET seismometers with standard traditional seismometers, the results (Fig. 2) demonstrate good and applicable noise spectrum over ~60 s to 20 Hz. In this effort we deployed the broadband MET sensor CME-6211 at the Incorporated Research Institutions for Seismology (IRIS) in NSF PASSCAL Instrument Center. Following several weeks of recording, we evaluated the time series data from several broadband sensors (Guralp CMG-3T, Streckheisen STS-2, and Trillium T120), in terms of overall sensitivity and response to ground motion, internal noise levels, and examination of raw data to compare seismograms sample by sample. This effort confirmed the benchmark testing capability of collaborating with PASSCAL and the good performance of non-MEMS MET seismometer provides us the confidence of our future success producing MEMS based micro MET seismometers.

Micro Sensing Element Development: Using

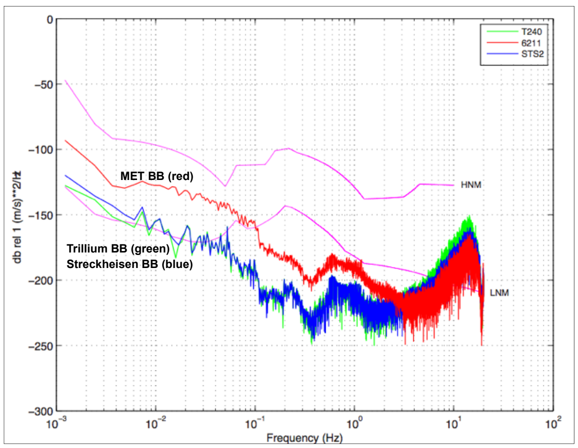

Fig.2: Noise spectra from the MET (red) and 2 other broadbands (blue and green)

standard silicon fabrication process, we have manufactured first generation of micro sensing elements for MET micro seismometers (Fig 3). The devices have reached noise floor of 45nG at 1Hz [5]. Further improvement is ongoing to target at <1nG for the noise floor.

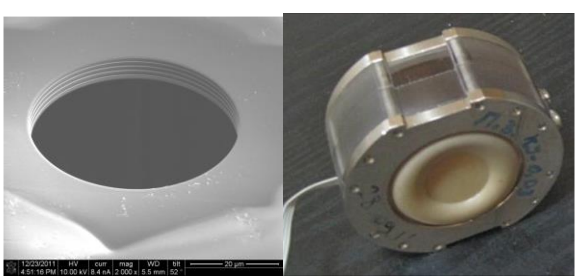

Fig.3: Sensing element and packaged sensor for MET micro seismometers.

Independence to orientation: A unique advantages of the MET seismometer is that it can be installed at any angle while retaining the same performance. We have verified the response by installing same single axis MET sensor in vertical, horizontal and 45° tilting angle. The measurements are comparable to a commercial tri-axis seismometer (Guralp 40T).

Shock tolerance: The sensing element is immersed in a liquid electrolyte, which produces a perfect mechanical buffer for the shock force. We have performed preliminary shock tolerance testing using the drop-test method. The results show that the device can survive at least 23.3 kG, where G is 9.8 m/s^2. While this level of shock is significantly beyond traditional seismometers, with an optimized design we expect to reach greater shock tolerances of 50 kG for planetary deployment as might be experienced by high speed penetrators.

Settle time: In comparison with tens of hours for traditional seismometers, our MET sensing unit with MEMS element needs less than 1 millisecond to settle. This provides extreme utility for fast mission operation when installation time is also a main factor of mission cost.

Harsh environemtal testing: High temperature (>100°C), low temperature (down to -181°C) and vacuum operation have been verified with thermal and vacuum chamber testing. The vacuum testing reveals that MET sensors have a better noise floor in vacuum than under ambient pressure. We found the limitation on operating temperature mainly from our water-based aqueous electrolyte; boiling will damage the device, and the sensors stop working at 90°C. Meanwhile, although it can recover functionality after warming up from freezing (-91°C), it will not function below -5°C. Improvement is under developing to widen the operation temperature range.

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