To provide a competitive actuating solution, micro-electromechanical-systems (MEMS)-based actuators need low operating power and form factors. Piezoelectrics provide substantially higher work-output/volume for a given voltage, when compared to other actuating solutions. A bow amplifier constructed of SU-8 beams and short length flexural pivots has been designed [1] and has demonstrated an amplification ratio of greater than 10:1. Current research focuses on increasing this amplification ratio and achieving the goal of 10% axial strain, while reducing parasitic out-of-plane bending inherent in the current fabrication process.

The overall goal of this project is to array one such actuator massively in series and in parallel in order to create a macro-scale, muscle-like actuator. Such a device would have widespread applications in mobile robotics, medicine, and aero/astronautics, where low power, high efficiency, and small form factors might be required.

REFERENCES
A Nanoscanning Platform for Biological Assays
S. Kim, S. Gouda, S.-G. Kim (P. So group)
Sponsorship: Intelligent Microsystems Center

An in-plane nanoscanning platform with switchable stiffness being developed at the Micro & Nano Systems Laboratory (MNSL) [1] can be an alternative to the existing atomic force microscope (AFM) system. The nanoscanning platform has a carbon nanotube (CNT) tip, which is known as one of the ideal candidates for AFM tips because of their superior mechanical and chemical properties. Raman Spectroscopy has gained a lot of interest as a tool for single molecule detection since it has easy and fast sample preparation and measurement compared to the existing technologies, such as X-ray crystallography and nuclear magnetic resonance. Among the several approaches attempted in order to enhance the weak Raman signals is tip enhanced raman spectroscopy (TERS). The enhancement of the electric field due to the plasmon resonance on the coated metal surface was predicted qualitatively [2]. The metal-coated CNT or CNT filled with Ag, Au, or Cu with a small diameter tip and high aspect ratio is ideal for TERS. The switchable stiffness AFM can work as a tool for imaging and placing the tip at the sub-nanometer proximity to a soft, molecular-scale biological sample, which would enhance the Raman signals.

**REFERENCES**


CNT Assembly by Nanopelleting

S.D. Gouda, S. Kim, S.-G. Kim
Sponsorship: Intelligent Microsystems Center

We have developed a novel method of manufacturing and assembling process termed nano-pelleting [1-2], which refers to large-scale handling and long-range order assembly of individual carbon nanotubes (CNTs). The nano-pelleting concept overcomes the limitation of very small-scale order by embedding carbon nanotubes into micro-scale pellets. This technique includes vertically growing single strand CNTs, embedding a CNT into a polymeric pellet, separating a pellet, and transplanting a CNT. The CNTs are grown vertically, both individually and in bunches, on the patterned catalytic metal using a plasma enhanced chemical vapor deposition (PECVD) machine (Figure 1) built by us at MIT. The machine’s key feature is the control of the substrate temperature during the growth process. At the bottom of the ceramic heater, three thermocouples are connected to measure the temperature, which is controlled by the heater controller. Plasma is formed between anode and cathode by applying a DC voltage, which then decomposes acetylene into carbon that deposits below the Ni catalyst and leads to the formation of carbon nanotubes. The process sequence to make pellets is the following: coating PMMA on the silicon wafer, exposing the photo-resists using Raith 150 to obtain the desired patterns by varying the aperture size, dose, electric field, developing the photo-resist, depositing Ti/Ni (25nm), and lifting-off the resist to obtain Ni-catalyst nano-dots. Single stranded CNTs are grown in the PECVD machine with optimized process conditions as shown in Figure 2. On these isolated CNTs, SU-8 is spin-coated to form a thickness of 25 micro-meter. This SU-8 layer is exposed to UV light using an appropriate mask and then developed to form nano-pellets. The nano-pellets are released from the silicon substrate by manually breaking them with a spark needle. We are developing an in-plane AFM probe [3] with mechanically assembled CNT tips.

REFERENCES
Self-powered Wireless Monitoring System Using MEMS Piezoelectric Micro Power Generator

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Sponsorship: NSF, Korean Institute of Machinery and Materials

A thin-film lead zirconate titanate Pb(Zr,Ti)O₃ (PZT), MEMS Piezoelectric Micro Power Generator has been integrated with a commercial wireless sensor, Telos, to simulate a self-powered RF temperature monitoring system (Figure 1). Such a system has many important applications, ranging from structure to rotary system monitoring. Telos consumes 2270 µJ for 221 ms per measurement. The PMPG and power management module are designed to satisfy such power requirements.

The first prototype of PMPG provides an average 1 µW, with a natural frequency of 13.9 kHz (Figure 2). It has an energy density of 0.74 mW-h/cm², which compares favorably to lithium ion batteries [1]. The second generation PMPG is designed to provide 0.173 mW of power at 3 V with a natural frequency of 150 Hz and maximum strain of 0.12% [2]. We increased the effective mass of the PMPG by adding a Si substrate with thickness of 525 µm to the beam structure. The increase in the effective mass increases the energy store in the device and its power output. The beam length is also increased to achieve a low resonant frequency. The third generation PMPG will use a serpentine structure, which can achieve a low frequency with minimum volume.

Since PMPG offers limited power, a storage capacitor and a power management module are implemented to power the sensor node at discrete time intervals [3]. The PMPG is first connected to a rectifier that converts AC to DC voltage. Each cycle consists of a charging interval, in which PMPG charges the capacitor, and operation intervals, in which Telos uses the energy from capacitor. We developed a test bed, which mimics that of a liquid gas pipe used in the Alaska where the PMPG device will be used to generate power for temperature sensors. Scaling/dimension factors as well as cost and robustness are considered in the design.

REFERENCES
MEMS Vibration Harvesting for Wireless Sensors

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Sponsorship: Cambridge-MIT Institute, NSF

The recent development of “low power” (10’s-100’s of µW) sensing and data transmission devices, as well as protocols with which to connect them efficiently into large, dispersed networks of individual wireless nodes, has created a need for a new kind of power source. Embeddable, non-life-limiting power sources are being developed to harvest ambient environmental energy available as mechanical vibrations, fluid motion, radiation, or temperature gradients [1]. While potential applications range from building climate control to homeland security, the application pursued most recently has been that of structural health monitoring, particularly for aircraft.

This SHM application and the power levels required favor the piezoelectric harvesting of ambient vibration energy. Current work focuses on harvesting this energy with MEMS resonant structures of various geometries. Coupled electromechanical models for uniform beam structures have been developed to predict the electrical and mechanical performance obtainable from ambient vibration sources. The uniform models have been validated by comparison to prior published results [2] and verified by comparison to tests on a macro-scale device [5]. Models of a uniform harvester with proof mass are currently undergoing macro-scale testing and validation. A non-optimized, uni-morph beam prototype (Figure 1) has been designed and modeled to produce 30 µW/cm³ [3]. A MEMS fabrication process for a prototype device is presented based on past work at MIT [4]. Dual optimal frequencies with equal peak powers and unequal voltages and currents are characteristic of the response of such coupled devices when operated at optimal load resistances (Figure 2). Design tools to allow device optimization for a given vibration environment have been developed for both geometries.

Future work will focus on fabrication and testing of optimized uni-morph and proof-of-concept bi-morph prototype beams. System integration and development, including modeling the power electronics, will be included.

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REFERENCES


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Figure 1: Illustration of MPVEH unimorph configuration (left) and SEM of a prototype device (right, courtesy of S.-G. Kim).

Figure 2: Power vs. normalized frequency with varying electrical load resistance [3].