Research Statement for Joseph R. Gladden

Experimental condensed matter physics is an incredibly diverse and exciting field in which significant research can be performed with "table top" experiments. I intend to establish a vigorous research program to explore mechanical properties of novel materials. Having helped develop a new experimental technique for measuring elastic properties of thin films deposited on a substrate using resonant ultrasound spectroscopy (RUS), I plan to apply the method to a wider variety of systems. As electronic and mechanical micro-device technology develops, characterization of materials at ever decreasing length scales becomes very important. Specifically, magnetic, superconducting, and structural phase transitions in thin films are of great interest. Such transitions can often be explored by other experimental techniques such as SQUID and transport measurements, however elastic constants are a sensitive probe into the atomic environment and thus very sharply reflect such transitions. For example, our work on colossal magnetoresistance films 200 and 400 nm thick has uncovered a previously unknown structural transition about 17 K above the known transition at the resistance peak. RUS data can be acquired relatively quickly and with minimal equipment by an experienced undergraduate or graduate student. Compared with other acoustic methods of determining elastic constants such as pulse-echo techniques, RUS shifts the emphasis from data acquisition to data analysis. The challenging part of the experiment is extracting the elastic tensor from the raw data, particularly for thin film experiments. Much of my doctoral work at Penn State focused on developing experimental procedures and computational tools for this analysis. The experiments we have performed to date have shown reasonable accuracy and excellent precision in measurements on films as thin as 200 nm.

The unique mechanical properties of carbon nanotubes suggest many potential applications. I have studied the effect of thin carbon nanotube films on energy dissipation in small solid state resonators. Typically a film added to a resonating solid will cause more energy to be dissipated per cycle, quantified by a drop in the quality factor Q. By depositing purified single wall nanotubes (SWNTs) on small resonators, we were surprised to find that the Q's *increased* by factors as high as six. This effect was found to be present in a wide variety of substrates including single crystals and alloys. I believe the increase in Q is caused by a reinforcement of surface microcracks and defects by the axially stiff SWNTs. As an extension to these results, I plan to study the effect of SWNT films on the fracture process in solids. It is known that the critical fracture stress of a solid increases with surface smoothness because there are fewer and smaller surface defects to act as seeds for the macroscopic fracture of the sample. Given the model stated above, the reinforcement of these defects due to the presence of SWNTs should have a dramatic effect on the fracturing process. Aspects of this study would include film thickness dependence, chemical functionalization of the SWNT/solid surface interface, and high speed video of the fracture dynamics.

I also have a number of interests in soft condensed matter. As a postdoctoral fellow working in the W.G. Pritchard Laboratory at Penn State, I have worked on several experiments related to the dynamic buckling and fracture in solids. The response of a slender rod to an impulsive load is to buckle with a characteristic wavelength. We derived a relation for this wavelength and have checked it's validity with high speed video. By shattering many brittle rods, we've obtained unique non-monotonic fragment size distributions which reflect the deterministic buckling process on the more random process of fragmentation and are currently making progress on a model to describe these statistics. Another experiment uses wormlike micellar (WM) gels, a unique viscoelastic material which is still poorly understood, to study fracture in a quasi 2D system. In contrast to cross-linked gels, WM gels are entropically bonded polymers so thermal cycling and time can heal structural damage. A useful feature of WM gels is strong birefringence, enabling sensitive visualization of stress fields. By moving a cutting tool, such as a cylinder, through the gel, very distinct stress fields emerge which are dipolar in nature and can be compared to electrostatic fields. The electrostatic analogy is helping us to understand the characteristic tearing patterns observed. The ability of the gel to relax on time scales of ~ 1 sec produces a rich phase plane of tool velocity and diameter. We have mapped three distinct regimes reflecting flow, cutting, and tearing behavior.

I plan to fabricate and study a novel material comprised of WM gels and ferrofluids producing an elastic magnetic gel. Initial studies would be centered around synthesis optimization, fundamental material properties, and dynamics. The introduction of the ferromagnetic microparticles may retard or inhibit the formation of the wormlike structure of the micelles critical to the elasticity in the material. If simple mixing methods are ineffective, it may be possible to mix the solution dilutely and concentrate by vacuum pumping. The effect of static and time dependent magnetic fields on mechanically excited dynamic properties, such as pattern formation in Faraday waves, can be explored, as well as stress patterns induced by such fields. Such dynamic control of the geometry inspires a number of potential applications, such as new mechanisms for micro fluid pumps and valves and artificial muscles.