NSF NER 2004: Novel group IV nanostructures in nature: Graphene starsmoke & Si intrusions

PROJECT SUMMARY

Vision and Goal

This proposal follows up on two connections encountered in our lab: One involves carbon nano-materials condensed in the atmosphere of asymptotic giant branch (AGB) stars, and the other involves impurity-triggered growth of interacting nano-structures at room-temperature on fresh silicon surfaces. The first connection focuses on a form of unlayered graphene, which may prove to: (i) be a significant player in absorption of light by carbon particles in the interstellar medium, (ii) offer evidence of carbon droplet-formation in cool stellar atmospheres with [C]>[O], and (iii) provide insight into processes of high-temperature carbon crystallization. The second connection involves a process that instead dominates in [C]<[O] star systems like ours, namely the reaction of silicon with oxygen that has run out of carbon to react with. Here, we follow up on recent reports of a subtle reaction under ambient conditions between fresh silicon surfaces and air. It creates 10[nm] intrusions beneath the native oxide with densities near 10^{10}[cm^{-2}] in a wide variety of freshly prepared silicon surfaces. Previous reports of larger intrusions after high temperature oxidation, following exposure of the Si surface to very small amounts of nickel and iron, suggest that these room temperature reactions may be catalyzed by very low concentrations of surface metal ions. Moreover, nucleation and growth of these defects after a short air exposure can be observed in situ by electron microscopy over laboratory time scales. Such intrusions may differ in composition and structure, and likely interact with one another via their impact on the surrounding silicon lattice. As such, they may provide a basis for adding "impurity-mediated self-assembly on 10[nm] size scales" to the arsenal of tools available along the *International Technology Roadmap for Silicon* in the next decade.

The graphene-related goals of this study are: (i) to formulate structural models of presolar graphene for comparison to lab and astrophysical observations, (ii) to acquire and analyze subangstrom-resolution images (e.g. from *Oak Ridge* and *Lawrence Berkeley* National Lab) from such material, and (iii) to look into comparison of both specimens and models with astrophysical data on the 2175[Å] interstellar extinction. The silicon-surface related goals of this study are: (i) to test wafer and fresh-epitaxial silicon surfaces with help from *MEMC Electronic Materials* (a major wafer manufacturer) as a function of intentional trace metal contamination, and (iii) to further characterize defect growth, nucleation kinetics, and strain in the microscope (e.g. as a function of air-exposure and temperature).

Broader Impacts

1. *Application to our understanding of nature*: Some fun questions are addressed here. In what form did carbon atoms on earth traverse the interstellar medium from their nucleosynthesis source? How do red giant stars persuade carbon to condense with healthy graphene sheets, but virtually no sign of graphite's van der Waals layering? How can 10[nm] oxide intrusions into silicon surfaces take hours to nucleate at room temperature, but only minutes to grow? Are silicon surfaces with the limiting 10^{10} intrusions per square centimeter in some way hardened by the interaction between adjacent defect strain fields?

2. *Application to manufacturing technology*: Industrial interest in unlayered graphene in the form of carbon nanotubes is growing, and of course the continuing economic importance of silicon surfaces e.g. to the electronics and software industries, on downward moving size scales in the 100[nm] range is well known. We propose here to address the issue of room-temperature transition-metal mediated nanostructure self-assembly. With help from focused ion beams, the whole periodic table may become available for self-assembly of devices on 10[nm] size scales in the years ahead.

3. *Application to education*: An awareness and understanding of processes on varying size scales, and of nano-microscopy techniques in particular, is of increasing importance to students in many fields (and citizens in many walks of life). We have an active program of involving undergraduate and graduate students in real explorations, as well as an active program of translating our laboratory experiences into web-based empirical observation challenges with storylines for use in existing courses on a variety of levels. This proposal will augment both of these activities.

The primary theme of this proposal is **Nanoscale Processes in the Environment**.