Nanoporous-Carbon for Gas Microsensors:
Correlating Growth Structures with Performance

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Gas-phase sensors for rapid detection of airborne chemicals, such as volatile and toxic organic compounds, and chemical warfare agents, are critical to public health and national security needs. Chemical sensors depend on sorbent coatings that are compatible with their operational environment, such as temperature, humidity, and chem-background. Such coatings need to be highly-sensitive, reproducible, manufacturable, and stable for long term use. Unfortunately, the prevalent polymer and sol-gel coatings used are constrained to sub-micron thicknesses, limiting the surface area available for sorption, and degrade with time and repeated thermal cycling.

Nanoporous-carbon (NPC) grows at room-temperature with negligible residual stress, therefore, it can grow to any thickness on any substrate. Since NPC is a purely graphitic material, it is chemically robust and stable to temperatures > 600 ˚C, well-above any thermal cycling used for devices. Indeed, NPC exhibits remarkable properties as a sorbing material for gas-phase microsensor applications.[Siegal et al, Langmuir, 2004] NPC is a purely graphitic material, nanocrystalline-to-amorphous in nature. To be useful as a sensing material in a surface acoustic wave (SAW) device, the material must have both high surface area and rigidity. NPC uniquely combines both of these critical properties.

We grow nanoporous-carbon (NPC) films using pulsed-laser deposition (PLD). Briefly, focused 248 nm excimer pulsed-laser radiation (KrF) ablates a rotating pyrolytic graphite target with energy density just above the carbon ablation limit. This energy density primarily controls the size of the carbon clusters that are used to grow a NPC film. To further attenuate the energy of the ablated carbon species, a controlled pressure of Ar is introduced into the PLD chamber during growth. The lower the kinetic energy of the ablated species, the lower the resulting average NPC mass density.

Fig. 1 shows the performance of SAW sensors detecting acetone absorbed into NPC films with varying density. This power-law relationship shows that while low density NPC has greater adsorption of acetone at high concentration, the poor rigidity of such material loses sensitivity at lower analyte concentrations. The slope of these adsorption isotherms predicts the ability of the coating to be sensitive to the lowest analyte concentrations. Clearly, the lower the slope, the more sensitive the coated-SAW device will be to low concentrations. This study will try to identify the fundamental materials properties influencing these slopes.

Fig. 2 shows that the acoustic loss of coated devices in air decreases with increasing mass density, i.e. the greater the film rigidity, the better the ultimate signal-to-noise ratios. Similar behavior is also observed for films with similar average mass density, but grown with various carbon cluster sizes (which leads to less homogeneous mass density). Fig. 2 shows that a relationship exists between the acoustic loss of a film (rigidity) with its ability to be sensitive to very dilute analyte concentrations.

We will present a detailed nanostructural analysis of the NPC coatings using both scanning and transmission electron microscopies, and correlate this information with network analysis of acoustic loss along with adsorption isotherms for several analytes.

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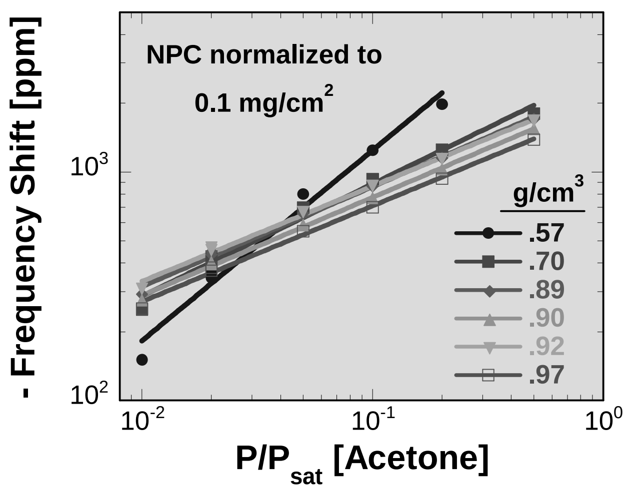

Fig. 1: Log-log representation of acetone adsorption isotherms from SAW sensor devices coated with varying average densities of NPC.

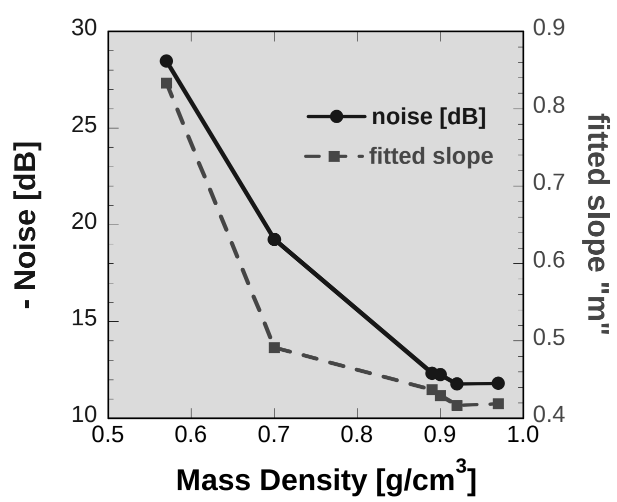

Fig. 2: Network analysis of SAW acoustic loss and the fitted slopes from fig. 1 as functions of average NPC mass density.