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NRL Formal Report Formats Using WordPerfect 5.1

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JUDY G. KOGOK
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*Publications Branch
Technical Information Division*

November 28, 1994

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NRL FORMAL REPORT FORMATS USING WORDPERFECT 5.1

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Header A

Select Format (Shift + F8), Page (2), Headers (3), Header A (1), Edit (5). Delete the words *Author's Name* and enter the appropriate name. If there are two or three authors, use their last names only. If there are more than three authors, use only the first author's name, followed by "et al." (example: Craigen et al.). Depress F7 to exit. (See Fig. 3.)

Header B

Select Format (Shift + F8), Page (2), Headers (3), Header B (2), edit (5). Delete the words *Brief Version of Title* and enter the appropriate report title. Depress F7 to exit. (See Fig. 4.)

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Fig. 1 — Coding for pages 1 and 2 of FRRH(U) file

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Fig. 2 — Footer A coding for page 1 (unclassified report)

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^B                                Author's Name

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[HLine:Left,Baseline,6.5",0.012",100%] [AdvDn:0.094"]

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Fig. 3 — Header A coding that begins on page 2 (unclassified report)

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Brief Version of Title                                ^B

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HRt]
[HLine:Left,Baseline,6.5",0.012",100%] [AdvDn:0.094"]

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Fig. 4 — Header B coding that begins on page 2 (unclassified report)

DIAMOND SURFACE CHEMISTRY

DIAMOND CHEMICAL VAPOR DEPOSITION

Diamond possesses numerous physical and chemical properties that have technological, industrial, and scientific applications. It has the highest thermal conductivity and hardness of any material, high optical transmission, a large bandgap and high carrier mobilities, and the lowest friction coefficient (under select conditions) [1,2]. These properties make diamond of particular interest to the electronics community for use as a heat spreader for thermal management or as an active electronics device material [3].

The current interest in diamond surface chemistry reflects recent advances in diamond growth by chemical vapor deposition (CVD), under what were once thought to be thermodynamically impossible conditions. Figure 1 is a schematic diagram of the CVD process [4]. CVD deposits diamond from a gas-phase mixture of hydrogen (H_2), hydrocarbon (usually methane, CH_4), and sometimes an oxygen-containing species or halogen (O_2 , CO , Cl_2 , HCl). The gases in the growth chamber are activated by various methods including microwave or radio frequency plasmas, DC discharge, combustion flame, or even a hot metal filament. All of these techniques fragment the hydrocarbon molecules to form a "soup" of hot hydrocarbon molecules and fragments. Most importantly, they split the hydrogen molecules into atomic hydrogen. The resulting hydrocarbon and atomic hydrogen species move through the reactor by diffusion and convection and impinge on the substrate. Adsorption, diffusion, reaction, and desorption of various species occur simultaneously on the substrate surface. Under a select set of conditions, diamond nucleates and grows while the deposition of graphitic (or sp^2) carbon formation is suppressed.

Hydrogen and oxygen play multiple roles in CVD diamond growth, both in the gas phase and on the surface of the growing film [5]. The principal effects of atomic hydrogen on the diamond growth process are thought to include: control of the gas phase chemistry, stabilization of the sp^3 -hybridized surface carbon atoms, preferential reaction with sp^2 -hybridized carbon, and abstraction of adsorbed hydrogen to produce reactive surface sites for carbon incorporation. Gas-phase hydrogen atoms (H) can adsorb on the surface and fill vacant sites or abstract surface hydrogen to form volatile molecular hydrogen. The desorbing hydrogen creates vacant surface sites and radicals at which methyl radicals and other hydrocarbon species adsorb and which are ultimately incorporated into the growing diamond lattice. The competing adsorption, desorption, and abstraction processes create a dynamic balance that leaves some open surface sites for addition while not completely denuding the surface of adsorbates. Such denuded (unterminated) surfaces rapidly develop double bonds and nucleate undesirable sp^2 -bonded carbon. Adsorbed hydrogen stabilizes the diamond surface and explains why diamond grows under CVD conditions. Oxygen species likewise bond at vacant surface sites and create open sites by desorbing or abstracting other surface species. At elevated temperatures, oxygen etches both sp^2 carbon (graphite) and sp^3 carbon (diamond) surfaces.

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2

Author's Name

The Diamond Surface

The diamond surfaces studied at NRL include both single crystals and polycrystalline films. The single crystals are either natural stones, man-made in a high-temperature/high-pressure (HTHP) press, or CVD-grown homoepitaxial layers on natural or HTHP stones. The homoepitaxial layers are especially useful since many natural and HPHT diamonds are insulating and hence unsuitable for many electron-based analyses because of surface charging. Small amounts of boron or other dopants introduced into the feedgas make the CVD-grown layers electrically semiconducting.

Diamond surface chemistry presents unique challenges and pitfalls. Surface chemistry in general, and CVD growth in particular, can occur principally at steps, ledges, and other defects. Crystals cut off-axis have higher densities of defect and ledge structures, which can lead to variable or unrepresentative data for surface reactions on a particular crystallographic surface. Commercially available diamonds are only cut to within 2° of the low-index ((100), (110), and (111)) faces, limiting their utility for some studies. Useful experiments require knowledge of how closely the sample surface matches the low-index planes and how smooth those surfaces are, along with confirmation that the surface remains essentially unchanged and uncontaminated by sp^2 carbon or other species during various treatments. The diamond grit polishing often used to finish diamond surfaces hinders formation of scientifically useful diamond surfaces by creating large numbers of microscopically rough surface wear tracks and pits. Sputtering and vacuum annealing techniques used in the surface science of metal crystals cannot be used because they convert the diamond surface to graphite. However, recent scanning tunnelling microscope (STM) work [6] and our own low-energy electron diffraction (LEED) and STM results show that (100) and (110) diamond surfaces heated to 800°C in a microwave hydrogen plasma become reproducibly smoother and well-ordered, with dramatically lower step and other defect densities. Such representative surfaces are proving highly useful for surface science and homoepitaxial growth studies.

Surface Analysis

Most of our experiments are conducted in ultrahigh vacuum (UHV) chambers with base pressures of $1\text{-}5 \times 10^{-10}$ Torr (Fig. 2). Independent heating and cooling capabilities allow control of the diamond surface temperature. Diamond surfaces at various temperatures are dosed with molecular hydrogen (H_2), deuterium (D_2 , an isotope of hydrogen), or oxygen (O_2) by backfilling the chamber. During some experiments, a tungsten filament heated to $>1800^\circ\text{C}$ excites H_2 or D_2 and dissociates a fraction of it to highly reactive atomic hydrogen (H) or deuterium (D). A hot (1150°C) iridium (Ir) filament excites molecular oxygen to more reactive vibrational and electronic states, and may convert some fraction to highly reactive atomic oxygen (O). The flux of atomic species to the diamond surface is unknown, so the doses listed are the total flux of the molecular species in Langmuirs ($1 \text{ L} = 10^{-6}$ Torr s).

We use a variety of electron-based, optical, and mass spectrometric techniques to interrogate the interactions between gas-phase species and diamond surfaces. Vibrational spectroscopies provide chemical bond information about adsorbates and surface structure. In high-resolution electron energy loss spectroscopy (HREELS), monochromatic low-energy electrons are scattered from the surface of interest and lose measurable amounts of energy through excitation of surface adsorbate and lattice vibrations. The specific amount of energy lost to these vibrations identifies the surface chemical species; the number of electrons losing that amount of energy reveals the surface coverage of that species. We obtain similar information with IR photons by multiple internal-reflection infrared spectroscopy (MIRIRS).

Auger electron and X-ray photoelectron spectroscopies (AES and XPS) provide compositional and chemical identification of the diamond surface (i.e., whether it is sp^2 or sp^3 bonded carbon and whether it is contaminated with other species) and give the type and extent of nonhydrogen surface termination.

Secondary electron emission (SEE) and electron loss spectroscopy (ELS) also confirm whether the surface is diamond or contains sp^2 carbon contamination. LEED measures the degree of surface order. Low-energy electrons scattered from a surface that consists of a regular array of atoms undergo constructive and destructive interference, which are observed as spots on a phosphor screen. The spot patterns are characteristic of the surface structure. The sharpness and contrast of the spots increase with respect to the background as the surface order improves. A differentially pumped, random flux-shielded, quadrupole mass spectrometer measures desorption products vs surface temperature in temperature programmed desorption (TPD) experiments. The adsorbate surface coverage after various treatments is obtained by integrating the area under the desorption curve. The combination of chemical species-specific probes (HREELS, AES, XPS, TPD) and techniques sensitive to surface structure (LEED, STM) provides a detailed picture of the diamond surface and adsorbates.

The LEED patterns from hydrogenated (110) faces also sharpen and brighten in a hydrogen plasma, indicating a smoother, more well-ordered surface. The background H_2 partial pressure impedes TPD measurement of hydrogen desorption from the diamond surface. For these studies, diamonds are exposed to D atoms created with the hot tungsten filament. TPD shows that neither molecular hydrogen nor deuterium react with bare diamond (110) surfaces at room temperature, but that atomic hydrogen and deuterium do chemisorb. Conversely, a deuterated surface heated to $1027^\circ C$ evolves molecular deuterium (D_2). We expect adsorption and desorption to be reversible processes. Therefore the adsorption of H(D) atoms and the desorption of H_2 (D_2) molecules indicates that molecular hydrogen requires additional energy (i.e., there is an activation barrier) to react with the bare surfaces.

REFERENCES

1. J.E. Field, *The Properties of Diamond* (Academic Press, N.Y., 1979).
2. R.F. Davis, Z. Sitar, B.E. Williams, H.S. Kong, H.J. Kim, J.W. Palmour, J.A. Edmond, J. Ryu, J.T. Glass, and C.H. Carter, Jr, "Critical Evaluation of the Status of the Areas for Future Research Regarding the Wide Band Gap Semiconductors Diamond, Gallium Nitride and Silicon Carbide," *Mat. Sci. Eng.* **B1**, 77 (1988).

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6. AUTHOR(S) R. Lucke, W. Shaffer, and R. Rhodes		8. PERFORMING ORGANIZATION REPORT NUMBER NRL/FR/6521--94-9508	
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13. ABSTRACT (<i>Maximum 200 words</i>) This report describes a Naval Research Laboratory software package for the simulation of surveillance by a spaceborne IR sensor. The simulation begins with data taken from airborne platforms and calculates the effects of the atmosphere, the time-varying sensor-to-scene observing geometry, and the optics and focal plane array architecture of the sensor to produce accurately simulated imagery. Signal processing techniques are then applied to suppress clutter and to detect moving airborne targets.			
14. SUBJECT TERMS IR surveillance Computer simulation		15. NUMBER OF PAGES 24	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED		16. PRICE CODE	
18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

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Fig. 6 — Header A coding for page 1 (classified report)

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Fig. 7 — Footer A coding for page 1 (classified report)

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^B                                Author's Name

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ble) 11pt] [HRT]
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Fig. 8 — Header A coding that begins on page 2 (classified report)

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Brief Summary of Title                                ^B

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Fig. 9 — Header B coding that begins on page 2 (classified report)

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Fig. 10 — Footer A coding that begins on page 2 (classified report)

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DIAMOND CHEMICAL VAPOR DEPOSITION

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*Author's Name***The Diamond Surface**

The diamond surfaces studied at NRL include both single crystals and polycrystalline films. The single crystals are either natural stones, man-made in a high-temperature/high-pressure (HTHP) press, or CVD-grown homoepitaxial layers on natural or HTHP stones. The homoepitaxial layers are especially useful since many natural and HPHT diamonds are insulating and hence unsuitable for many electron-based analyses because of surface charging. Small amounts of boron or other dopants introduced into the feedgas make the CVD-grown layers electrically semiconducting.

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Surface Analysis

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Brief Summary of Title

3

((U) paragraph continues)

it is contaminated with other species) and give the type and extent of nonhydrogen surface termination. Secondary electron emission (SEE) and electron loss spectroscopy (ELS) also confirm whether the surface is diamond or contains sp^2 carbon contamination. LEED measures the degree of surface order. Low-energy electrons scattered from a surface that consists of a regular array of atoms undergo constructive and destructive interference, which are observed as spots on a phosphor screen. The spot patterns are characteristic of the surface structure. The sharpness and contrast of the spots increase with respect to the background as the surface order improves. A differentially pumped, random flux-shielded, quadrupole mass spectrometer measures desorption products vs surface temperature in temperature programmed desorption (TPD) experiments. The adsorbate surface coverage after various treatments is obtained by integrating the area under the desorption curve. The combination of chemical species-specific probes (HREELS, AES, XPS, TPD) and techniques sensitive to surface structure (LEED, STM) provides a detailed picture of the diamond surface and adsorbates.

The LEED patterns from hydrogenated (110) faces also sharpen and brighten in a hydrogen plasma, indicating a smoother, more well-ordered surface. The background H_2 partial pressure impedes TPD measurement of hydrogen desorption from the diamond surface. For these studies, diamonds are exposed to D atoms created with the hot tungsten filament. TPD shows that neither molecular hydrogen nor deuterium react with bare diamond (110) surfaces at room temperature, but that atomic hydrogen and deuterium do chemisorb. Conversely, a deuterated surface heated to $1027^\circ C$ evolves molecular deuterium (D_2). We expect adsorption and desorption to be reversible processes. Therefore the adsorption of H(D) atoms and the desorption of H_2 (D_2) molecules indicates that molecular hydrogen requires additional energy (i.e., there is an activation barrier) to react with the bare surfaces.

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