

GENERAL PHYSICS

I. MOLECULE MICROSCOPY

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RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

Joint Services Electronics Program (Contract DAAB07-71-C-0300)

National Institutes of Health (Grants 1 PO1 HL14322-02 and 5 SO5 RR07047-08)

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Introduction

There are three kinds of microscopy characterized by the particles that carry information concerning the sample to the observer. Photons and charged particles have been used extensively in well-known ways, but the possibility of obtaining information from neutral molecules emitted by a sample in vacuum has apparently not been exploited. The idea of building a microscope that uses neutral molecules to obtain an image arose from our studies of evaporation from liquid helium. The molecule microscope, although useful in many fields of science and engineering, seems likely to prove most important in materials science and biology. This is because molecules carrying information from the sample interact through the same weak forces that are significant in determining surface properties, and because the interactions are highly surface-specific (in contrast to photons and electrons which penetrate many atomic layers).

In a general way we would propose that the term "molecule microscope" be reserved for instruments that use neutral molecules leaving the sample to produce a picture or micrograph. Thus spatial variation in the permeation of molecules through a thin sample, binding of applied neutral molecules to a sample surface, and existence of constituent molecules can all be revealed directly by some type of molecule microscope. Scientific and technological problems relating to both materials science and biology appear ripe for investigation by molecule microscopy. The materials science aspects of the problems have been supported by the Joint Services Electronics Program, and the biological applications by the National Institutes of Health.

Objectives

We are building various prototype molecule microscopes and plan to apply them to significant problems in materials science and biology. Among these problems we shall study the following.

1. Grain boundary permeabilities in germanium.
2. Binding of small molecules to carbon black.
3. Surface staining as a means of identifying surface sites in various materials.
4. Transport of gases and vapors in both synthetic and biological membranes.

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Summary of Research

1. Scanning Pinhole Molecule Microscope (SPMM)

A prototype Scanning Pinhole Molecule Microscope using H₂O molecules as the illuminant,¹ has been built and operated. This first instrument was difficult to operate and, having demonstrated the basic principle, is no longer in use. Two new molecule microscopes are almost complete, and we are making initial studies for several supporting experiments. Simple calculations show that the ultimate resolution can reach the 10-100 Å range.² A more detailed report of our progress follows.

An improved version of the first prototype has the following features. (i) Spatial resolution has been improved. The first SPMM had a resolution of ~200 μm, whereas this apparatus will have an initial resolution of ~10 μm, and ultimately ~1 μm. (ii) A high-transmission mass spectrometer is included so that molecule micrographs can be made with more than one molecular species and sensitivity to other residual gases can be reduced. (iii) An improved vacuum system with considerable cold surfaces for cryopumping has been included. We expect to start initial tests on this SPMM early in 1974.

We are also planning a materials science experiment in cooperation with Professor A. Witt of the Department of Metallurgy, M.I.T. Our first experiment will be a study of grain boundary permeability variations in germanium. A thin (~10 μm) sample will be used, with vacuum (the SPMM) on one side and a moderate pressure of H₂ on the other. In addition to furnishing good spatial resolution, the SPMM can also be used in a nonmicroscope mode. Here only the rapid time response of the instrument is used. We plan to use the apparatus in this mode to study vascular smooth muscle with the aid of Dr. J. W. Peterson, and Dr. F. Fay of the University of Massachusetts Medical School, in Worcester.

2. Scanning Desorption Molecule Microscope (SDMM)

The first SDMM, also scheduled for completion early in 1974, is being constructed primarily by H. F. Dylla. In this apparatus a scanning electron beam, initially a few micrometers in diameter, is provided by an electron optical column designed by Dr. J. W. Coleman of our group. (A separate report² will be made by J. C. Weaver.) Neutral molecules can be applied to the sample either before or while they are in the SDMM, and will constitute a neutral molecule surface stain.¹ By subsequent desorption of the stain molecules, we expect to obtain a picture of the spatial variation in binding sites for the stain molecules, an approach that should be important to surface science in general. Initial experiments will probably use H₂O molecules as a stain on test specimens such as germanium in the investigation with Professor Witt, and on nylon (modeling a biological type of surface) in order to map out hydrophilic sites.

The Quadrupole Mass Spectrometer for the SDMM has been in use for several months, and the electron optics column has been assembled. The vacuum system is almost finished, with initial tests of the completed apparatus anticipated soon. Also, preliminary tests of electron stimulated desorption (ESD) for the SDMM are being carried out by H. F. Dylla.

3. Desorption Experiments Related to SDMM

In order to construct and use the SDMM successfully, a basic understanding of appropriate desorption mechanisms and means of controlling them is essential. Several experimental efforts are directed toward this goal.

First, an experimental apparatus has been constructed by D. G. Lysy to develop neutral molecule surface staining for organic chemical and biological surfaces. Basically,

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the apparatus has several platinum ribbons, each of which can be coated with an organic molecule to provide a test surface. Stain molecules can be applied and subsequently desorbed, either by ohmic heating of the platinum ribbon or locally by an electron beam. This apparatus is essentially completed, and initial tests are under way.

Second, an apparatus to study the use of alkali atoms as surface stains has been built by B. R. Silver. In this case a standard hot wire is used instead of an electron bombardment "universal ionizer." It is of considerable interest to learn whether a spatial correlation of Na and K exists in transporting tissue, and this problem will provide the long-range motivation for this approach. Of more immediate interest is testing the range of validity of heat pulse calculations for thermal desorption in SDMM. Such calculations can be tested by using thin organic samples coated with a thin film of K, and thermally desorbing the potassium under different conditions. This apparatus is operating in its initial form, and valuable experience has been gained by measuring the binding energy of potassium to a tungsten ribbon.

Third, S. Jost is beginning to construct an apparatus to study the binding of stain molecules such as propane to carbon filaments. Such interactions are technologically important, primarily in the design of better rubber tires, and collaboration with Dr. D. Rivin of Cabot Corporation has been initiated. Similar studies substituting silicon-based fibers may lead to understanding of the binding of petroleum molecules to sand grains and rock, which may possibly be of interest in the recovery of petroleum from tar sands and oil shale.

References

1. J. C. Weaver and J. G. King, Proc. Nat. Acad. Sci. U.S. 70, 2781 (1973).
2. J. C. Weaver, "Factors Affecting Resolution of Scanning Desorption Molecule Microscopy," to appear in Quarterly Progress Report No. 113, April 15, 1974.

