A SIMS STUDY OF THE INFLUENCE OF LOW LEVELS OF SILICON AND CALCIUM ON THE... (U) TEXAS UNIV AT AUSTIN DEPT OF CHEMISTRY S AKHTER ET AL. 15 OCT 85 TR-43
OFFICE OF NAVAL RESEARCH

Contract No. N00014-83-K-0582

Task No. NR 056-578

TECHNICAL REPORT NO. 43

A SIMS Study of the Influence of Low Levels of Silicon and Calcium on the Adsorption Properties of O₂ on Pt(111)

by

S. Akhter, C. M. Greenlief, H.-W. Chen and J. M. White

Prepared for publication in

Applied Surface Science

Department of Chemistry
The University of Texas at Austin
Austin, Texas 78712

Reproduction in whole or in part is permitted for any purpose of the United States Government.

This document has been approved for public release and sale; its distribution is unlimited.
A SIMS Study of the Influence of Low Levels of Silicon and Calcium on the Adsorption Properties of $O_2$ on Pt(111)

A SIMS STUDY OF THE INFLUENCE OF LOW LEVELS OF SILICON AND CALCIUM ON THE ADSORPTION PROPERTIES OF O\textsubscript{2} ON Pt(111)\textsuperscript{a}

S. Akhter, C. M. Greenlied, H.-W. Chen and J. M. White
Department of Chemistry
University of Texas
Austin, Texas 78712

ABSTRACT

Surface impurity levels of Ca, Si and Al, which are at or below the detectability limits of Auger electron spectroscopy, have been followed in secondary ion mass spectrometry (SIMS) and correlated with oxygen adsorption on Pt(111). It is shown that oxidation of Si to SiO\textsubscript{2}, monitored by the rise in the SIMS Si\textsuperscript{+} ion intensity, takes place above 500 K during oxygen TPD. The SiO\textsubscript{x} starts decomposing above 1100 K and can be reduced within 200 sec. by 2x10\textsuperscript{-8} torr of H\textsubscript{2} at 1200 K. The molecular, atomic and total amount of oxygen adsorbed/desorbed in a temperature programmed desorption (TPD) cycle depends on the immediate past history of the impurity levels on the surface. In particular, the presence of SiO\textsubscript{2} is correlated with an increase in the overall sticking coefficient of oxygen. These results highlight the importance of impurity levels below the detectability limits of AES and suggest pretreatment methods for obtaining better reproducibility.

(a) Supported in part by the Office of Naval Research.
1. INTRODUCTION

There have been a number of reports regarding the role of Si in the formation of the high temperature "oxide" state on Pt(111) and the catalytic properties of that state. The various findings have been summarized [1-3]. Following the work of Kislius and Comsa [1, 2] and Bonsel et al. [3], it became clear that a Pt(111) surface could be considered clean if, after oxidation at ~1000 K, no oxide state (due to Si) could be detected in AES. Typically a surface is deemed "clean" by AES if impurity levels are below its detectability limits (~0.01 ML). While this may be acceptable in most cases, it is, nevertheless, important to characterize impurities at even lower levels and to examine their significance in surface processes.

Several other interesting observations have been attributed to Si or SiO_x. Segner et al. [4] reported better thermal accommodation of CO_x with a Pt(111) surface in the presence of the "oxide" state. Another interesting observation made by Mundschau and Vaneel [5] is that the silicon impurity in platinum can stabilize (210) planes on a field-emitter tip. Yeates et al. [6] report that the presence of silicon was necessary to observe oscillatory behavior during CO oxidation on Pt(111) at atmospheric pressure.

Recently, we have been engaged in using secondary ion mass spectrometry (SIMS) as a tool for kinetic studies. In the course of these studies on Pt(111), we noted variations in the impurity ion levels in static SIMS, depending on the immediate past history of the sample, although, by AES, the surface was considered clean and no changes could be observed. Oxygen desorption areas from this surface, after different pretreatments, showed variations as high as 30%, even if all experiments were done within an hour. This pointed to a significant effect of impurities, which were at or below Auger detectability limits.

We report here a systematic study of the silicon, calcium and aluminum positive SIMS signals and their variation with oxygen and hydrogen dosing and with argon sputtering treatments of the platinum surface. The desorption of oxygen is correlated with the levels of these signals.

In the previous investigations of Kislius and Comsa [1, 2] and Bonsel et al. [3], the following important observations were made:
(a) The location of Si and SiO_x is subsurface at low concentrations.
(b) The equilibrium amount of segregated Si declines rapidly above 900 K.
(c) The rate of segregation is very slow below 900 K.
(d) The equilibrium amount, but not the rate, of segregated Si is enhanced in the presence of oxygen.
(e) The presence of Si could be more reliably inferred from the presence of the AES oxygen peak after oxidizing Si to SiO_x than from AES of Si.

These observations provided a framework on which our experimental design is based. It should be pointed out that in the above investigations, large amounts of Si were deposited and diffused in the bulk. In the present report, small variations in Si and other impurity levels were achieved by heating the sample at 1200 K for variable times. In the following sections, the Si that is accessible to oxygen and affects its adsorption properties, is simply referred to as "surface silicon."
2. EXPERIMENTAL

The experiments were performed in a turbo-pumped UHV system equipped
with a double pass CMA for AES and a quadrupole mass spectrometer having
SIMS capabilities. Pressures of 3x10⁻¹⁰ Torr were regularly obtained. The
Pt(111) sample could be heated to 1300 K and cooled to 100 K with liquid
nitrogen. The temperature was measured with a chromel-alumel thermocouple.
The SIMS spectra were taken in line-of-sight of the quadrupole with a 600 eV
beam of less than 2 nA of Ar⁺ current rastered over the surface.

3. RESULTS AND DISCUSSION

3.1 The SIMS Si⁺ ion

Fig. 1 shows typical SIMS and AES spectra of a "clean" surface,
selected arbitrarily out of our data. The SIMS spectrum shows a number of
impurity ions including Na⁺, Mg⁺, Al⁺, Si⁺, K⁺ and Ca⁺. The Al⁺, Si⁺ and
Ca⁺ ions were always present and it was not possible to eliminate them
completely. The AES spectrum shows no evidence of these impurities (AES
impurity/substrate ratio 0.01). In particular, the absence of Si and O
(due to SiO₂) are noted. The inset shows the maximum amount of
"oxide"(O/P₄₃₇ = 0.08) that was ever seen during the experiments reported
here.

At the outset we ask whether the Si⁺ ion is from elemental Si or SiOₓ.
We have focused on the Si impurity because of its known affinity for oxygen
on Pt(111). To resolve this issue, the surface was heated in vacuum at
1000 K for 15 minutes and oxidized to segregate as much SiOₓ as possible.
The segregated SiOₓ was then partially reduced to Si by heating in 2x10⁻⁸
torr of H₂ at 1200 K for 200 secs. The temperature was then decreased to
650 K. The SIMS Si⁺ count on this surface is shown by the initial portion
(0 to 100 secs.) of the curve in Fig. 2. The Auger scans of the O(KLL) and
Pt(237) regions are also shown. The surface was then exposed to 2x10⁻⁸ torr
of oxygen at 650 K. The Si⁺ signal increased immediately upon exposure and
slowly saturated. Since the diffusion of Si to the surface at 650 K is very
slow [3], the observed increase in Si⁺ signal is ascribed to the oxidation
of pre-existing surface silicon to SiOₓ. This was confirmed by flashing off
only the adsorbed oxygen. The Si⁺ signal did not change. Thus we conclude
that the enhancement described above was due to SiOₓ, not chemisorbed
oxygen. Furthermore, an AES scan taken after flashing off adsorbed oxygen
(1000 K) shows a small amount of residual oxygen, attributed to the "oxide"
state (Fig. 2). This confirms the presence of SiOₓ and also suggests a
relation between the Si⁺ ion intensity and the presence of the oxide state.
We conclude that for very low levels of silicon on Pt(111), the SIMS Si⁺ ion
is predominantly from SiOₓ and can be used as a measure of the SiOₓ
concentration. The Si concentration can be indirectly measured by
completely oxidizing it to SiOₓ at low temperatures. Further evidence for
our conclusion will become apparent during later discussions.

3.2 Formation and stability of SiOₓ

SiOₓ can be formed by continuous exposure of the surface to oxygen
above 400 K [3], as shown in Fig. 2. It also forms during an oxygen TPD
cycle. In Fig. 3, oxygen was adsorbed, at 100 K, on a Pt(111) surface,
which had been subjected to one adsorption/desorption cycle after sputtering
and annealing. The temperature was ramped at 5.5 K/s to 1060 K and held there for a few minutes. The Si' ion intensity gradually increases up to about 900 K. Again, the increase is attributed to the oxidation of Si to SiO₂ because the diffusion of Si to the surface is very slow at lower temperatures. The increase in Si' intensity above 500 K is also consistent with the fact that O(a) becomes mobile above that temperature [5] and thus is able to react with Si more readily.

The SiO₂ also yields the "Si™O" ion (m/e = 44) which was confirmed by oxidizing in "O₂, after which the "Si™O" ion (m/e = 46) was observed. The SiO₂ is reasonably stable up to 1100 K, but it starts to decompose at higher temperatures, as evidenced by the decline in both "Si™" and "Si™O" signals when a surface exhibiting a relatively high Si' signal, was temperature programmed (Fig. 4). The decline is not due to diffusion into the bulk, because the Si was initially segregated at a higher temperature (1200 K). Also, most of the Si' intensity may be recovered by reoxidizing at low temperatures, which suggests that the Si is still in the surface region. The reason for the peak in the Si' intensity before its final decline above 1100 K is not clear. It may be connected with SiO₂ rearrangement before decomposition.

Heating in 2×10⁻⁸ torr of H₂ at 1200 K for 200 sec. was sufficient to reduce nearly all the SiO₂ to Si, as shown by the disappearance of the Si' ion in the SIMS spectra of Fig. 5. For higher concentrations of SiO₂ (observable in AES), the above treatment was not sufficient. Longer reduction times and/or sputtering was required to completely remove the SIMS Si' signal.

It was also noted that the Ca²⁺ ion (m/e = 40) disappeared upon reduction (after H₂ treatment in Fig. 5) while the Ca' ion intensity was enhanced. This contrasting behavior is reconciled if the Ca²⁺ ion is attributed to CaO (which is present before reduction) and the Ca' ion being mainly from elemental Ca. Such a correlation between the charge of the ion and its valence state on the surface has been observed frequently.[9] That the m/e = 40 ion was due to "Ca" and not "K²⁺" was confirmed by reducing in D₂ (instead of H₂) in which case no m/e = 41 ("K²⁺") ion was observed.

3.3 Oxygen adsorption: Impurities at AES detection limit

A set of experiments was performed to study the dependence of oxygen adsorption on the impurity levels of Si, SiO₂, Ca etc. It was considered necessary to observe SiO₂ in AES, so as to establish its existence and determine an upper limit of its concentration.

The surface was sputtered and then annealed at 1200 K to segregate some silicon. 10 L of oxygen (1×10⁻⁷ torr, 100 secs.) was adsorbed at 100 K and subsequently desorbed by flashing to 1000 K. After that, the surface was alternately oxidized (1×10⁻⁷ torr O₂, 700 K, 900 secs.) and reduced (2×10⁻⁸ torr H₂, 1200 K, 200 secs). After each treatment, an AES scan, a SIMS scan and an oxygen adsorption/desorption cycle were performed. The results are shown in Fig. 6, where the desorbed oxygen amounts and the SIMS and AES impurity signals are plotted against the pretreatment run number (O₂ oxidation, H₂ reduction, Ca sputter cleaned). A good correlation is observed between the changes in the amount of oxygen desorbed and the variation in the impurity levels as observed by SIMS and AES. It is noted that oxidation to form SiO₂ (increase in Si' intensity) leads to an increase in oxygen desorption. Reduction produces Si (decline in Si') and a decrease in O, desorbed. The O/Pt(237) ratio corresponding to the "oxide" state is also shown. The maximum value of this ratio in these experiments was 0.08.
A good correlation between the maxima in the O/Pt ratio and the maxima in the Si' counts is also noted. The Al' ion behaves like the Si' ion. The Ca' ion intensity, on the other hand, decreased upon oxidation and increased on reduction. This might suggest that the Ca' intensity is primarily due to elemental Ca (Ca' ion yield is not enhanced by oxygen). In the AES scans, Ca and Al were not seen, except in the second oxidation experiment of Fig. 6, where a small amount of Ca was detected (Ca/Pt<sub>237</sub> = 0.03).

From the present set of experiments, we conclude that the oxygen adsorption/desorption properties of Pt(111) are dependent on the immediate past history of the impurity levels. We tentatively attribute the above variations in oxygen uptake to alternate oxidation and reduction of Si, although we cannot rule out effects due to Ca and Al. We note, however, that the changes in oxygen adsorption were observed after pretreatments (oxidation and reduction conditions) that are known to effect changes in the chemical state of Si [1-3].

The effect of impurities is further demonstrated by the results of Fig. 7. In this series of experiments, consecutive O<sub>2</sub> adsorption/desorption was performed (7 times), starting from a sputter-cleaned and annealed surface. Before and after each desorption, SIMS spectra were recorded. The O<sub>2</sub> exposure in each experiment was 10 L at 100 K and the TPD was terminated at 1000 K. The desorption areas from the first experiment are arbitrarily set to 100 and, thus, the ordinate represents the per cent increase in desorption area. The results correlate the amount of O<sub>2</sub> desorbed and the intensities of Si' (SiO<sub>2</sub>'), Ca' and Al' ions. The amount of O<sub>2</sub> desorbed and the Si' and Al' intensities increase monotonically while the Ca' ion intensity decreases continuously. With the considerations outlined above in mind, we discuss these results in terms of changes in the state of Si. From Fig. 7, the conversion of Si to SiO<sub>2</sub> (increase in Si' intensity) leads to greater oxygen adsorption in the same adsorption time; that is, the overall sticking coefficient is enhanced in the presence of SiO<sub>2</sub>. Alternatively, it may be argued that the presence of Si decreases the overall sticking coefficient. These two effects cannot be separated, based on our results.

After run #6 of Fig. 7, an AES scan revealed a small amount of oxygen due to the "oxide" (O/Pt<sub>237</sub> = 0.06). Before run #7, the sample was heated in H<sub>2</sub> (2×10<sup>-8</sup> torr, 1200 K, 200 sec.) to reduce SiO<sub>2</sub> to Si. Both the Si' intensity and the amount of desorbed oxygen decline, as expected from the behavior in preceding runs.

Our best estimate of the maximum amount of Si present in this series of experiments (evaluated from the O/Pt<sub>237</sub> ratio after run #6) is 0.025 ML, assuming SiO<sub>2</sub> stoichiometry and an O/Pt<sub>237</sub> ratio of 0.3 for 0.25 ML O(a) on Pt(111). [8] The latter is reasonable since, for saturation amounts of atomic oxygen, we obtained O/Pt<sub>237</sub> ratios between 0.3 and 0.4.

The oxygen TPD peak positions were in agreement with previous investigations [8]. The molecular state desorbed in a sharp peak at 140 K and the atomic state desorbed between 640 and 670 K depending on the oxygen coverages attained in the above sequential adsorption experiments. Generally, the peak due to the atomic state became wider and the peak position shifted to lower temperatures as the oxygen uptake increased in each subsequent adsorption. The effect, if any, of Ca, Si and Al on the position and shape of the atomic peak is difficult to discern. All changes are consistent with the second order nature of the atomic peak.
3.4 Oxygen adsorption/desorption: Impurities below AES detectability limits

The dependence of oxygen adsorption on impurity levels below the detectability limits of AES was also investigated. The series of experiments in section 3.3 were repeated on a surface which did not show any detectable "oxide" in AES (O/Pt\_237 = 0.01) after 7 oxygen TPD cycles. As before, 10 L of oxygen was adsorbed at 100 K and followed by a TPD to 1000 K. The results are shown in Fig. 8. The data again show that the amount of oxygen desorbed and the Si' , Ca' and Al' ion intensities are correlated.

As before, we discuss these results in terms of changes in the state of Si. The overall sticking coefficient of oxygen is enhanced when the Si is oxidized to SiO\_x. The major difference between the high impurity level (section 3.3) and low impurity level results is that in the former case the total amount of oxygen desorbed increases by 50% while in the latter the increase is only 15% in going from an unoxidized (elemental Si) to oxidized (SiO\_x) surface. Unfortunately, the relative quantities of oxygen desorbed in the two cases (high and low impurity levels) cannot be directly compared because these experiments were done at different times, between which the chamber had been opened, and the detector sensitivity was not the same.

4. CONCLUSIONS

Based on the results discussed above, the following conclusions are made:

(i) A Pt(111) surface deemed "clean" by AES may still contain surface impurities that have a detectable influence on kinetic phenomena. The use of SIMS extends the lower limit of the cleanliness criterion.

(ii) (Near) surface Si is readily oxidized to SiO\_x during oxygen TPD. The SIMS Si' ion can be used to follow the oxidation process.

(iii) Oxygen adsorption on Pt(111) at 100 K is dependent on the impurity levels which are determined by the immediate past history of the sample.

(iv) The presence of SiO\_x (absence of Si) enhances the overall sticking coefficient of oxygen on Pt(111).

(v) The reproducibility of oxygen uptake improves as the elemental silicon impurity level drops.

These results suggest that cleaning Pt(111) surfaces should involve sputtering with repeated O\_2 exposures and SIMS analysis until Si' and SiO' levels drop to very low values. Residual Si should be oxidized prior to experiments involving oxygen or oxygenated compounds in order to obtain stable adsorption properties.

The presence of SiO\_x enhances the uptake of oxygen. The mechanism involved is probably electronic, as the Si atoms near SiO\_x may be considered to be supported on it, as suggested by Neithus and Comsa [1].
REFERENCES


FIGURE CAPTIONS

Fig. 1: AES and SIMS spectrum of a "clean" Pt(111) surface. A 1.8 nA and 600 eV Ar⁺ ion beam was used for the SIMS scan. The inset represents the maximum "oxide" (corresponding to O/pt\textsuperscript{237} of 0.08) that was seen during this work.

Fig. 2: Growth of the Si⁺ ion intensity on exposure to 2×10⁻⁸ torr of O₃ at 650 K. Ar⁺ beam was 0.9 nA at 600 eV. AES spectra of the O(1KLL) and Pt⁺⁺ regions are also shown.

Fig. 3: Growth of the Si⁺⁺ ion intensity during O₃ TPD. 10 L of O₃ was adsorbed at 100 K and temperature programmed at 5.5 K/s to 1050 K. Ar⁺ beam = 1.5 nA at 600 eV. The arrow marks the onset temperature (-500 K) of mobility of O(a) on Pt(111) [5].

Fig. 4: Decline of Si⁺⁺ and SiO⁺⁺ ion intensities on heating in vacuum above 1100 K. The sample was previously oxidized during a number of oxygen adsorption experiments with \textsuperscript{18}O₂. Ar⁺ beam = 1.5 nA at 600 eV.

Fig. 5: SIMS spectra of an oxidized surface before and after N₂ treatment (1200 K, 2×10⁻⁸ torr). The amount of SiO₂ was below AES detectability. Ar⁺ beam = 1.8 nA at 600 eV.

Fig. 6: Changes in (a) SIMS impurity ion intensities, (b) "silicon oxide" O/pt\textsuperscript{237} AES ratio and (c) oxygen desorption areas as function of
pretreatment. O = oxidised at 700 K with 1×10^{-7} torr of O, for 900 sec.
R = reduced at 1200 K with 2×10^{-8} torr of H, for 200 secs. C = sputtered
clean and annealed at 1200 K for 500 secs. After each pretreatment, 10 L of
O, was adsorbed at 100 K and temperature programmed at 5.5 K/s until 1000 K
to generate the TPD spectra. After each oxidation pretreatment the sample
was flashed to 1000 K to remove any adsorbed oxygen, before performing the
AES and SIMS scans.

Fig. 7: Changes in SIMS impurity ion intensities and O, desorption areas as
function of consecutive oxygen adsorption/desorption cycles. In each case
10 L of O, was adsorbed at 100 K and temperature programmed at 5.5 K/s, to
1000 K. Before run #7 the sample was reduced in 2×10^{-8} torr of H, at 1200 K
for 200 sec. Each of the O, desorption areas (and the total) in the first
run are arbitrarily normalized to 100. Ar beam = 0.8 nA at 600 eV.

Fig. 8: Changes in SIMS impurity ion intensities and O, desorption area as a
function of consecutive O, adsorption/desorption cycle. 10 L of O, was
adsorbed at 100 K and the sample was heated at a rate of 5.5 K/s to 1000 K.
No SiO, impurity was detectable in AES after run #7 (O/Pt=0.01). Each of
the O, desorption areas (and the total) in the first run are arbitrarily
normalized to 100. Ar beam = 1.5 nA at 600 eV.
Pt(111)  
SiO_x Decomposition

**Fig 4**

<table>
<thead>
<tr>
<th>Temperature, K</th>
<th>Ion Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>430</td>
<td></td>
</tr>
<tr>
<td>650</td>
<td></td>
</tr>
<tr>
<td>870</td>
<td></td>
</tr>
<tr>
<td>1090</td>
<td></td>
</tr>
<tr>
<td>1310</td>
<td></td>
</tr>
</tbody>
</table>

041.

**Fig 5**

Pt(111)  
H_2 treatment
2 x 10^{-8} torr
1200 K
200 secs

BEFORE H_2 treatment  
Ca^{2+}, Na^+, Mg^+, Al^3+, Si^+, K^+

AFTER H_2 treatment  
Na^+, Mg^+, Al^3+, Si^+, K^+

SIMS Ion Counts

720 Counts/s/nA
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>City, State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. F. Carter</td>
<td>Naval Research Laboratory</td>
<td>Washington, D.C. 20375</td>
</tr>
<tr>
<td>Dr. Richard Colton</td>
<td>Naval Research Laboratory</td>
<td>Washington, D.C. 20375</td>
</tr>
<tr>
<td>Dr. Dan Pierce</td>
<td>National Bureau of Standards</td>
<td>Washington, D.C. 20234</td>
</tr>
<tr>
<td>Dr. A. Stanley Williams</td>
<td>Department of Chemistry</td>
<td>Los Angeles, California 90024</td>
</tr>
<tr>
<td>Dr. R. P. Messmer</td>
<td>Materials Characterization Lab.</td>
<td>Schenectady, New York 22217</td>
</tr>
<tr>
<td>Dr. Robert Garner</td>
<td>Department of Chemistry</td>
<td>Chicago, Illinois 60637</td>
</tr>
<tr>
<td>Dr. Ronald Lee</td>
<td>Naval Surface Weapons Center</td>
<td>White Oak, Maryland 20910</td>
</tr>
<tr>
<td>Dr. Paul Schoen</td>
<td>Naval Research Laboratory</td>
<td>Washington, D.C. 20375</td>
</tr>
<tr>
<td>Dr. John T. Yates</td>
<td>Department of Chemistry</td>
<td>Pittsburgh, Pennsylvania 15260</td>
</tr>
<tr>
<td>Dr. Richard Greene</td>
<td>Naval Research Laboratory</td>
<td>Washington, D.C. 20375</td>
</tr>
<tr>
<td>Dr. L. Kesmodel</td>
<td>Department of Physics</td>
<td>Bloomington, Indiana 47403</td>
</tr>
<tr>
<td>Dr. K. C. Janda</td>
<td>California Institute of Technology</td>
<td>Pasadena, California 91125</td>
</tr>
<tr>
<td>Dr. E. A. Irene</td>
<td>Department of Chemistry</td>
<td>University of North Carolina Chapel Hill, North Carolina 27514</td>
</tr>
<tr>
<td>Dr. Adam Heller</td>
<td>Bell Laboratories</td>
<td>Murray Hill, New Jersey 07974</td>
</tr>
<tr>
<td>Dr. Martin Fleischmann</td>
<td>Department of Chemistry</td>
<td>Southampton University Southampton 509 SW Hampshire, England</td>
</tr>
<tr>
<td>Dr. John W. Wilkins</td>
<td>Laboratory of Atomic and Solid State Physics</td>
<td>Ithaca, New York 14853</td>
</tr>
<tr>
<td>Dr. Richard Smrzewski</td>
<td>Naval Research Laboratory</td>
<td>Washington, D.C. 20375</td>
</tr>
<tr>
<td>Dr. H. Tachikawa</td>
<td>Chemistry Department</td>
<td>Jackson State University Jackson, Mississippi 39217</td>
</tr>
<tr>
<td>Dr. G. A. Somorjal</td>
<td>Department of Chemistry</td>
<td>University of California Berkeley, California 94720</td>
</tr>
<tr>
<td>Dr. J. Murray</td>
<td>Naval Research Laboratory</td>
<td>445 Overlook Avenue, S.W. Washington, D.C. 20375</td>
</tr>
<tr>
<td>Dr. J. B. Hudson</td>
<td>Materials Division</td>
<td>Rensselaer Polytechnic Institute Troy, New York 12181</td>
</tr>
<tr>
<td>Dr. Theodore E. Madey</td>
<td>Surface Chemistry Section</td>
<td>National Bureau of Standards Washington, D.C. 20234</td>
</tr>
<tr>
<td>Dr. J. E. Demuth</td>
<td>IBM Corporation</td>
<td>Thomas J. Watson Research Center P.O. Box 218 Yorktown Heights, New York 10598</td>
</tr>
<tr>
<td>Dr. M. G. Legally</td>
<td>Department of Metallurgical and Mining Engineering</td>
<td>University of Wisconsin Madison, Wisconsin 53706</td>
</tr>
<tr>
<td>Dr. R. P. Van Duyne</td>
<td>Chemistry Department</td>
<td>Northwestern University Evanston, Illinois 60207</td>
</tr>
<tr>
<td>Dr. J. M. White</td>
<td>Department of Chemistry</td>
<td>University of Texas Austin, Texas 78712</td>
</tr>
<tr>
<td>Dr. D. E. Harrison</td>
<td>Department of Physics</td>
<td>Naval Postgraduate School Monterey, California 93940</td>
</tr>
<tr>
<td>Dr. W. Kohn</td>
<td>Department of Physics</td>
<td>University of California, San Diego La Jolla, California 92037</td>
</tr>
<tr>
<td>Dr. R. L. Park</td>
<td>Director, Center of Materials Research</td>
<td>University of Maryland College Park, Maryland 20742</td>
</tr>
<tr>
<td>Dr. W. T. Perle</td>
<td>Electrical Engineering Department</td>
<td>University of Minnesota Minneapolis, Minnesota 55455</td>
</tr>
<tr>
<td>Dr. Keith H. Johnson</td>
<td>Department of Metallurgy and Materials Science</td>
<td>Massachusetts Institute of Technology Cambridge, Massachusetts 02139</td>
</tr>
<tr>
<td>Dr. S. Stibner</td>
<td>Department of Chemistry</td>
<td>James Franck Institute 5640 Ellis Avenue Chicago, Illinois 60637</td>
</tr>
<tr>
<td>Dr. Arnold Green</td>
<td>Quantum Surface Dynamics Branch</td>
<td>Code 3817 Naval Weapons Center China Lake, California 93555</td>
</tr>
<tr>
<td>Dr. A. Wold</td>
<td>Department of Chemistry</td>
<td>Brown University Providence, Rhode Island 02912</td>
</tr>
<tr>
<td>Dr. S. L. Bernasek</td>
<td>Department of Chemistry</td>
<td>Princeton University Princeton, New Jersey 08544</td>
</tr>
<tr>
<td>Dr. P. Lund</td>
<td>Department of Chemistry</td>
<td>Howard University Washington, D.C. 20059</td>
</tr>
<tr>
<td>Office of Naval Research</td>
<td>Co. 413</td>
<td>Arlington, Virginia 22217</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Dr. Bernard Doua</td>
<td>Naval Weapons Support Center</td>
<td>Code 5042</td>
</tr>
<tr>
<td>Commander, Naval Air Systems Command</td>
<td>Attn: Code 310C (M. Rosenwasser)</td>
<td>Washington, D.C. 20360</td>
</tr>
<tr>
<td>Naval Civil Engineering Laboratory</td>
<td>Attn: Dr. R. W. Drisko</td>
<td>Port Hueneme, California 93401</td>
</tr>
<tr>
<td>Defense Technical Information Center</td>
<td>Building 5, Cameron Station</td>
<td>Alexandria, Virginia 22314</td>
</tr>
<tr>
<td>DTNSRC</td>
<td>Attn: Dr. G. Bosmajian</td>
<td>Applied Chemistry Division</td>
</tr>
<tr>
<td>Dr. William Tolles</td>
<td>Superintendent</td>
<td>Chemistry Division, Code 6100</td>
</tr>
<tr>
<td>Dr. David Young</td>
<td>Code 334</td>
<td>NORDA</td>
</tr>
<tr>
<td>Naval Weapons Center</td>
<td>Attn: Dr. Ron Atkins</td>
<td>Chemistry Division</td>
</tr>
<tr>
<td>Scientific Advisor</td>
<td>Commandant of the Marine Corps</td>
<td>Code RD-1</td>
</tr>
<tr>
<td>U.S. Army Research Office</td>
<td>Attn: CRO-AAR</td>
<td>P.O. Box 12211</td>
</tr>
<tr>
<td>Mr. John Boyle</td>
<td>Materials Branch</td>
<td>Naval Ship Engineering Center</td>
</tr>
<tr>
<td>Naval Ocean Systems Center</td>
<td>Attn: Dr. S. Yamamoto</td>
<td>Marine Sciences Division</td>
</tr>
</tbody>
</table>