Photoelectron Emission from Solid Ne Quenched by He Impurities

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Abstract An effect of He adsorption on the photoelectron yield from the solid Ne subjected to VUV radiation is studied. Electron emission is measured using cyclotron resonance of free electrons. The bulk He impurity in Ne is found to have negligible effect on the yield. The results of the study suggest that the quenching of emission by He flow fed to a low temperature substrate during Ne condensation is attributable to He atoms adsorbed on the Ne surface. A model is proposed for the surface sites responsible for ejection of electrons.

Keywords He atoms, adsorption, ECR, electron emission

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1. INTRODUCTION

It has been shown recently [1], that the unstable centers obtained with the use of a conventional X-band EPR spectrometer [2,3], were due to cyclotron resonance of free electrons (ECR) emitted from a solidified gas layers subjected to irradiation from an electrodeless open gas discharge. A Ne discharge has been applied in most runs. Subsequent experiments carried out with the solid Ne irradiated by the light of an open Ne discharge showed that a flow of He gas supplied to the substrate avoiding a gas discharge zone decreased the ECR amplitude [4]. The decrease has been attributed to different mechanisms at the sample temperatures of 4.2 K and 1.6 K. He monolayer formation on the Ne surface was suggested in low temperature region. Indeed, despite the pronounced quantum properties of He and semiquantum properties of Ne, the possibility of the He coverage for a solid Ne substrate was shown to occur by Shirron et al. [5] and Csáthy et al. [6]. A conclusion about a major role of the surface He impurities was made [4] based on the qualitative comparison of the efficiency of helium cryotrapping by the solid Ne condensed on the substrate at 4.2 K and 1.6 K. The present study is aimed at giving quantitative evidence to the above suggestion. Also we present results of a treatment of the ECR curves [4] which suggest occurring of some special Ne surface “active” sites where electrons escape into the vacuum.

2. EXPERIMENTAL DETAILS

The setup and experimental procedure have been presented in detail elsewhere [1, 3]. Briefly, they are as follows. Free electrons yielded into a pumped cavity from the sample, were observed through the electron cyclotron absorption using a conventional EPR device [1, 4]. The bottom of a quartz finger filled with liquid helium serves as a low temperature substrate for the gases being condensed. The bottom is located at the center of the microwave cavity of an X-band EPR spectrometer. The cavity is evacuated and cooled externally with liquid nitrogen vapor which provides a
cavity temperature from 77 to 300 K. An electrodeless high-frequency (15 MHz) discharge operated in a pulsed regime is excited in the gaseous Ne which is passed through a glass tube with an outlet of approximately 0.6 mm diameter. The products of the discharge enter the cavity and condense on the bottom, forming a Ne solid. The solid is irradiated from the outlet, which, therefore, operates as an open discharge source. The helium gas flows to the substrate through a quartz tube inserted into the cavity. The tube bypasses the discharge zone. The end of the quartz tube is located close (3 mm) to the substrate. Both gases are cooled with liquid nitrogen vapor prior to deposition. The substrate temperature is lowered down by pumping the liquid He bath. The base pressure in the experimental chamber is 2 × 10⁻⁶ Torr. Pure gases were used with the following nominal impurity contents: 0.004% Ne and 0.01% He. The pump is operated during the experiment to remove gaseous He from the cavity and cryostat.

3. RESULTS

The occurrence of the impurity helium cryotrapping by solid Ne during the sample condensation was evident [4] not only at T_{dep} = 1.6 K, the lower temperature in the study, but at the higher one, T_{dep} = 4.2 K. In the experiments, the pressure magnitudes in two different spots of the vacuum system were measured which gave an information about the rate of He flow and pumping efficiency of the Ne sample at the cryogenic temperatures. The first one was a pressure of helium, \( p \), at the warm end of the tubing which supplied the gaseous He to the substrate. This warm end was attached to a needle valve which governed \( p \) and, hence the He flow. The flow might be assessed by the gas amount consumed from the storage container. Figure 1

![Graph](image)

**Fig. 1.** The figure verifies a linear dependence \( q(p) \), where \( p \) is a pressure measured at the warm end of tubing supplying the flow, \( q \), of gaseous He to the low temperature substrate

confirms the linear dependence between \( p \) and the rate of He flow, \( q \). The second one was a helium pressure in the cavity, \( p_{He} \), which reflected a balance between the flow entering the cavity and the net pumping speed due to simultaneous action by a pumping facility and the cold substrate. The dependence \( p_{He}(p) \) was measured [4] to be non-linear for small He flows
provided to the Ne sample at 4.2 K. Since the ability of the solid Ne to absorb He is restricted, $p_{He}(p)$ dependence eventually becomes linear at large enough He flows. To obtain a formula fitting the experimental data, let assume that a portion of the Ne surface covered by He layer adsorbs no He atoms. Then $S_{free}$ and $S_{ocup}$ be the surface areas free of adsorbed He atoms or occupied by these atoms, respectively. It is reasonable to assume that $S_{free}/S_{ocup}$ is proportional to $p_{Ne}/p_{He}$, where $p_{Ne}$ is the pressure of gaseous Ne in the cavity:

$$S_{free}/S_{ocup} = \gamma p_{Ne}/p_{He}$$  \hspace{1cm} (1)

Here $\gamma$ is the proportionality coefficient.

The flow of He pumped through the cryotrapping, $q_{tr}$, is proportional to $S_{free}p_{He}$ and can be shown to depend on $p_{He}$ as

$$q_{tr} \sim \frac{p_{He}}{1 + \frac{p_{He}}{p_{Ne} \cdot \gamma}}$$  \hspace{1cm} (2)

with $S_{free}$ given by an expression

$$S_{free} \sim \frac{1}{1 + \frac{p_{He}}{p_{Ne} \cdot \gamma}}$$  \hspace{1cm} (3)

It turns out that the back flow of He atoms desorbed into the vacuum, $q_{des}$, follows the same dependence as $q_{tr}$. Summing up $q_{tr}$, $q_{des}$ and the flow through the pump, $q_{1}$, one obtain the net He flow, $q_{0} \sim p$, passed into the cavity from the gas container. Eventually we obtained the fitting expression:

$$p(p_{He}) \sim p_{He} + \frac{b \cdot p_{He}}{1 + c \cdot p_{He}}$$  \hspace{1cm} (4)

where $b$ and $c$ are adjustable parameters.
Fig. 2. Cryopumping of impurity He by Ne sample during the sample condensation on the substrate at 4.2 K. The solid line is drawn using expression (4) which accounts for both types of pumping: by the condensing Ne and by the pump assembly. The dashed line is for the cryopumping only.

Figure 2 shows that the experimental points are well fitted by the above expression. The second term of Eq. (3) describes the cryopumping by the Ne surface, while the first one is related to the pumping by the pump assembly attached to the cryostat.

Based on the result presented in figure 2 we estimated a portion of the He flow trapped in the condensing solid Ne as ¾ for $p = 1.33$ Pa. Thus, at small flows, the major part of gaseous He entering the cavity is trapped by the Ne sample at 4.2 K becoming eventually the bulk impurity. On the other hand, no $p_{He}$ increase with increasing $p$ was observed for the sample temperature of 1.6 K [4] which means that all gaseous He was pumped off by the cold sample. Therefore, at small He flows, both the 4.2 K and 1.6 K samples contained nearly equal concentrations of trapped He atoms. This suggests that the drop in the ECR signal intensity for samples at 1.6 K which started at $p$ of about 0.01 torr and was not observed for the 4.2 K sample cannot be assigned to the He bulk impurities which, thus, have either small or no effect on the photoelectric yield. Particularly, no exciton induced photoemission from impurity He takes place. Interestingly, the induced photoemission from the bulk impurities was observed earlier for Xe in Kr and Ar, and for Kr in Ar [7], that is for systems where a solid has the higher ionization potential than an impurity particle, a situation opposite to the one considered in the present paper.

Thus exactly the surface He atoms on the Ne sample cause the decrease of the photoelectron yield. The fitting of $A(p)$ may testify this assumption and provide valuable information on the process of photoelectron emission. To obtain the fitting formula, it seems reasonable to suppose that the emission takes place from the surface regions which are not occupied by the adsorbed He atoms. The larger the area of these regions, $S_{free}$, is, the stronger the ECR signal intensity, $A$. So, the $A(p)$ dependence is expected to resemble the expression (2). Since almost all He atoms entering the cavity are trapped in the sample at 1.6 K, we may replace $p_{He}$ with $p$ because of the proportionality of $p$ and $p_{He}$. Finally we come to the fitting expression in the form:

$$A(p) = \frac{b_1}{1 + c_1 \cdot p} + a_1$$

(5)
Fig. 3. Decrease of an amplitude of the ECR signal upon increasing He flow to the substrate at 1.6 K. Fitting curves: dashed line is for expression (5); solid line is for expression (6) with $d_2 = 2.3$.

The component $a_1$ accounts for the fact that the new Ne layers which appear again and again through the condensation are sufficiently “hot” to absorb He atoms until thermalization takes place. Therefore no “screening” occurs at these areas and the electrons are allowed to live the sample. Figure 3 shows the result of the fitting procedure. While the fitting curve follows the experimental points in general, the agreement between the experiment and theoretical model is insufficient for large He flows and should be improved for the moderate flows. What is worse, the component $a_1$ turned out to be negative, an outcome which has no physical meaning. Therefore, we modified the expression for $A(p)$ as follows:

$$A(p) = \frac{b_2}{1 + c_2 \cdot p^{d_2}} + a_2$$

(6)

The analysis gave us the best fitting value of $d_2$ equal to 2.30(26) with other positive adjustable parameters. The best $d_2$ close to 2 leads to the suggestion about the origin of the surface sites from which the electrons escape the sample. Indeed, the component $c_1 p$, Eq. (5), came from the fact that $S_{\text{free}}/S_{\text{ocup}}$ ratio is inversely proportional to $p$ for the flat surface (terrace sites), Eq. (1). Let suppose that the electrons escape, actually, from the regions near the line where two Ne planes cross (step sites). We will consider the area to be “free of adsorbed He atoms” if each of the plane contains no He atoms in the close vicinity of the line they cross along. Then, the Eq. (1) is modified as:

$$S_{\text{free}}/S_{\text{ocup}} = \chi (p_{\text{Ne}}/p_{\text{He}})^2$$

(7)

In that case we will obtain $A(p)$, Eq. (6), with $d_2 = 2$. Possibly, these special regions (where electrons leave the sample) are atomic step sites (step edges) at the Ne surface which are responsible for the sample growth. Figure 4 shows the fitting errors plotted against the power $d_2$. The figure gives a hint that not only step edges are responsible for the electron emission but, possibly, three-coordinated surface sites – corners and kinks also.
Figure 4. Fitting errors for the experimental data plotted in figure 3 and fitted according to expression (6) with various values of $d_2$ power.

4. CONCLUSIONS

The experimental results and their treatment discussed in the present work revealed the key role which the surface plays in the process of photoelectron emission from rare gas solids. Also we were able to show that the bulk impurities have negligible effect on the emission compared to the surface ones. The discussion of the models of the active surface sites outlined above suggests that the flat surface is inactive in the photoemission which occurs, most probably, through the low-coordinated surface sites. The effects found in the present study are related to radiation-induced charging in polycrystalline insulating materials. Recently, it was demonstrated, by first-principles calculations that the surface trapping of electrons occurs even in negative-electron-affinity materials [8, 9]. By examining insulators like MgO, LiF and NaCl, the authors showed that low-coordinated sites and grain boundaries may act as traps for conduction-band electrons. The calculations are substantiated by experimental findings on UV desorption of neutral Mg and O atoms from particular MgO sites [10, 11]. The proposed mechanism of desorption involves localization of excitons as well as electrons and holes at three-coordinated surface sites – corners and kinks. The mechanism of quenching photoemission from solid Ne by surface atomic He is, however, not clear at present and requires a thorough further research. One may suppose that an electron affinity, $EA$, of a guest particle may play a certain role. According to some studies published so far the $EA$ of helium atoms is slightly positive, while is found slightly negative in other published works. To check the above suggestion about the effect of $EA$ on quenching photoemission from solid Ne, we plan experiments using different kinds of impurities with larger magnitude of $EA$, positive and negative as well.

REFERENCES