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# SURFACE PHONONS IN THE 1/F NOISE OF A DISCONTINUOUS PLATINUM FILM

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In a discontinuous platinum film, the 1/f noise intensity does not smoothly depend on temperature but features a fine structure consisting of kinks and peaks. Some of these singularities are tentatively associated with the specific platinum surface phonon energies. If correct, this observation considerably supports the participation of the surface atomic motion in the generation of 1/f noise.

*Key words:* platinum films, discontinuous, 1/f noise, phonons.

## 1. INTRODUCTION

Since its first observation by Johnson in a vacuum diode [1], 1/f noise, where f is the frequency, has been observed in such a large diversity of systems that it is now considered one of the most ubiquitous physical phenomenon ever known. In solid-state physical systems, the origin of this phenomenon is still a question of much debate, although it has been investigated for more than 70 years. A longstanding and very controversial issue is whether 1/f noise is a surface or a bulk effect. Introduced by McWhorter [2], the idea that 1/f noise is a surface effect is specific to semiconductors and semiconductor devices. That is because in this microscopic model, the 1/f noise is attributed to the fluctuation in the number of carriers due to their tunneling into interface/oxide states. For other physical systems, such as metals, McWhorter model cannot explain the experimental results. In this context, Hooge proposed [3] that 1/f noise is not a surface but a bulk effect. Later on, based on some experimental data, Hooge and Vandamme [4] concluded that phonon scattering is the microscopic source of the 1/f noise. In favour of this hypothesis, bulk phonons participation in the 1/f noise of silicon [5],[6], metallic films[7],[8] and quartz [9],[10] has been reported. Moreover, attempting [11] to explain the anomalous behaviour of the 1/f noise in discontinuous platinum film under about 200K [12], a fine structure has been evidenced in the dependence of the noise intensity on temperature. This structure has been associated not only with bulk phonons but also with some surface atomic vibration modes. From this interpretation, it is apparent that also surface is involved in the generation of 1/f noise. Therefore, a discontinuous metal film is a suitable solid-state physical system to verify the hypothesis of surface phonons participation in the generation of 1/f noise.

In this contribution we report the observation of a phonon-fine structure in the temperature dependence of the 1/f noise spectral density of a discontinuous platinum film. The structure will be associated mainly with the energies of the platinum surface phonons, thus proving that the surface atomic motion contributes to the 1/f noise.

## 2. RESULTS AND DISCUSSION

The investigated sample was a discontinuous, 4×2 mm$^2$ and aprox. 80Å thick, platinum (Pt) film. During the noise measurement, the film was maintained in the high vacuum (l0$^{-9}$mbar) deposition system. The sample was biased by a current generator (a battery in series with a low-noise resistor). The voltage noise signal from the platinum resistor terminals was fed into a low noise, battery-operated amplifier (Stanford Research, SR 560). The amplified noise signal was Fourier analyzed with an HP 3562A dynamic signal analyzer and the spectra (noise intensity, $S_v$) were registered with a digital plotter. Even at lower

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temperature, where the film resistance is high, the equilibrium resistance noise was very low (e.g.: $8\times10^{-10}V^2/Hz$ at 107K ), so that no subtraction was necessary.

Generic $1/f^{\alpha}$ noise has been observed in the investigated Pt film, with $\alpha$ very close to 1. An example of such a spectrum is shown in figure 1. It has been obtained by averaging 15 snap-shot spectra, at a temperature of 117K corresponding to the first peak in the noise intensity vs. temperature (see also Fig. 2). For frequencies lower than $10^4$Hz, the shape of the spectrum is almost purely 1/f.

The dependence of the voltage noise spectral density ($S_v$) on temperature, for a frequency f=10Hz, is shown in figure 2. Each point in Fig. 2 has been obtained by averaging 15 snap-shot spectra. A fine structure composed of peaks and kinks is visible in the noise vs. temperature plot. It should be noted that for temperature lower than 155K, the noise dependence on temperature is quite similar to the one reported for the 1/f noise parameter of copper [7] and gold films [8]. Following the procedure outlined in Refs [7] and [8], the temperature (T) of each singularity was multiplied by the Boltzmann constant ($k_B$) and the corresponding energy ($k_BT$) was tentatively associated with the platinum phonon energies determined by other methods. The results are comparatively presented in the Table I. The peak located at 117K (10meV) corresponds to the lowest surface phonon energy at the $\overline{M}$ point of symmetry of the platinum surface Brillouin zone, as observed by Kern *et al.* [13] by inelastic scattering of the He atoms. The next three singularities are in good agreement with the platinum surface phonon energies at $\overline{K}$ and $\overline{M}$ points of symmetry, respectively, as determined by Harten *et al.* [14]. Note that the third singularity (12.1meV) fits also well with the energy of a transversal bulk phonon [15], while the 5th singularity (13.3meV) is in a close agreement with a bulk phonon energy (13.4meV) [15]. The broader but well defined peak at 14meV (163K) is in excellent concordance with a surface phonon energy (14meV) at the $\overline{M}$ point [14]. Finally, the kink at 15.2meV (176K) might be easily associated with the energy of a surface phonon at the $\overline{K}$ point (15meV) [13]. For temperature higher than 185K, some burst noise pulses were observed in the noise signal trace, therefore no reliable 1/f noise measurements were possible.

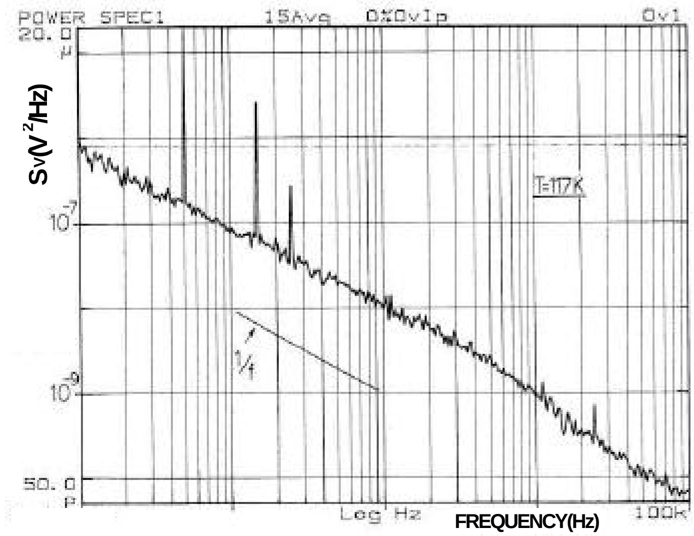


Fig.1 - The noise spectral density ($S_v$) of the voltage developed across the platinum resistor terminal at 117K; this temperature corresponds to the first peak in the dependence of $S_v$ vs. temperature (see Fig. 2).

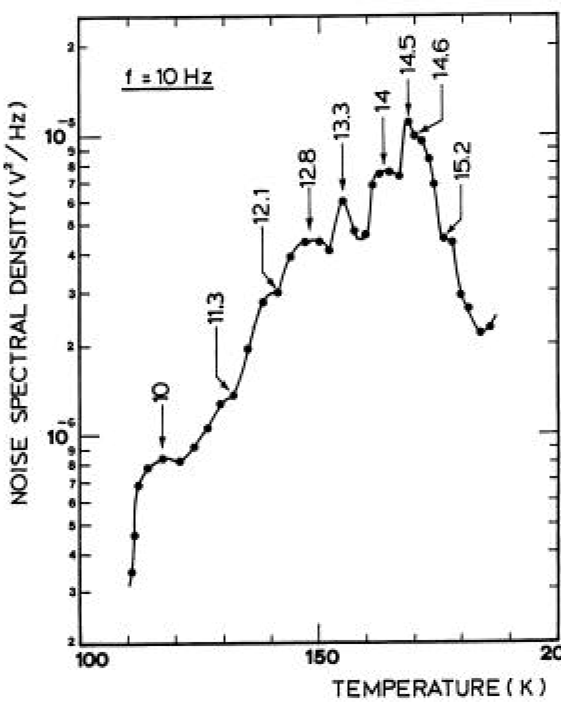


Fig. 2 - The noise spectral density ($S_V$) vs. temperature. The arrows indicate the position and the corresponding energy (in meV) of each singularity in the noise.

As for the *maximum maximorum* located at 170K (14.6meV), we suspected that some adsorption-desorption processes of residual complex molecules [12] were responsible for its occurrence and, as a first guess, one notes that according to Fisher and Gland [16], for low initial coverage (e.g.: 0.25 langmuirs), the water desorption from Pt surface exhibits a peak at about 170K. Also, Celasco et al. [12] reported a water desorption peak at about 165K. One can thus speculate that the *maximum maximorum* in the noise spectral density could originate in the residual water molecules desorption but the mechanism involved in the noise generation is still obscure. In this respect, the experiments of Klausgrete and Storm [17] undoubtedly demonstrated that the noise intensity in Pt wires depends on the nature of the adsorbate. Therefore, the mechanism of noise could reside in the interaction of the molecules with the substrate. Since the "accommodation and sticking of atoms and molecule's is governed by the coupling to the phonon heat bath at the surface" [18], the desorption-induced 1/f noise could be a phonon-mediated one. Consequently, the energy associated with the maximum (14.6meV) would correspond to an adsorbate-enhanced Pt phonon, although we were not able to identify it to date.

Table I – Comparison between the phonon energies determined from 1/f noise measurement and inelastic helium/neutron scattering

| Peak number | Temp.[K] | $k_BT$ from noise [meV] | Other methods [meV] | Assignation | Ref. |
|---|---|---|---|---|---|
| 1 | 117 | 10 | 10 | Surface phonon at $\bar{\mathbf{M}}$ | 13 |
| 2 | 132 | 11.3 | 11.1<br>11 | Surface phonon at $\bar{\mathbf{K}}$<br>Surface phonon at $\bar{\mathbf{K}}$ | 14<br>13 |
| 3 | 141 | 12.1 | 12.2<br>12 | Surface phonon at $\bar{\mathbf{K}}$<br>$[\frac{1}{2}\frac{1}{2}\frac{1}{2}]$T bulk phonon | 14<br>15 |
| 4 | 148 | 12.8 | 12.8 | Surface phonon at $\bar{\mathbf{M}}$ | 14 |
| 5 | 155 | 13.3 | 13.4 | $1\frac{1}{2}0$ $\lambda$ bulk phonon | 15 |
| 6 | 163 | 14 | 14 | Surface phonon at $\bar{\mathbf{M}}$ | 13 |
| 7 | 170 | 14.6 | - | Adsorbate-enhanced Pt phonon? | - |
| 9 | 176 | 15.2 | 15 | Surface phonon at $\bar{\mathbf{K}}$ | 13 |

From the above considerations, it results that the presence of the residual gas molecules on the metal surface affects the noisiness of the substrate they are sitting on. For instance, by repeating the measurement, we have found that the noise intensity slightly increases with the exposure time (the time the sample is kept at the lowest temperature attainable), especially for temperature lower than 155K. Moreover, while the whole structure is reproducible, the associated temperatures slightly decreased (about 3K) with the exposure time. Therefore, increasing the exposure time, more molecules are accumulated on the film surface. Their presence would modify the vibration frequency of the surface atoms, so that if the observed structure is phonon-induced one would expect small shifts in the position of the noise peaks/kinks. Consequently, the observed infrared shift supports the idea of surface phonons participation in the 1/f noise.
On the other hand, extending these experiments could be very beneficial in investigating the dynamic of the adsorbed molecule. It is interesting to note that the presence of the adsorbed molecules was the key assumption in the first model of 1/f noise elaborated by Schottky in 1926 [19]. However, the mechanism we propose for the 1/f noise generation, namely phonon-carrier interaction, is in contrast with his assumption.

## 3. CONCLUSIONS

A fine structure consisting of kinks and peaks has been observed in the 1/f noise spectral density of a discontinuous platinum film. The energies corresponding to these singularities have been correlated mainly with the specific surface phonon energies of platinum. Two of them were also associated with bulk phonon energies. The possible influence of the residual adsorbates on the 1/f noise was also discussed. These results demonstrate that both surface and bulk phonons are involved in the 1/f noise generation. On the other hand, these results point to the 1/f noise measurement as a possible tool to investigate the vibrational state of the adsorbates on solid surface.

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