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A TIP OSCILLATION PHENOMENON

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RESUME : Une étude des coues stables des pointes en microscopie électronique à transmission montre l'existence d'une oscillation des pointes avec des amplitudes de ~ 200 Å et des fréquences de ~ 0.3 Hertz (Cu, Au, 900°C). L'oscillation est expliquée par une interaction de deux forces : (1) une force électro-statique causée par l'impact des électrons et annihilée par une décharge d'émission de champ et (2) une force élastique d'une couche graphitique à la surface de la pointe.

ABSTRACT : A detailed study of stable tip necks by in situ transmission electron microscopy shows an existence of tip oscillations with amplitudes in the order of 200 Å and frequencies in the order of 0.3 Hertz (Cu, Au at ~ 900°C). The oscillation is explained by an interaction of two forces : (1) an electrostatic force caused by electron impact and annihilated by a field emission discharge and (2) an elastic force of a graphitized layer on the tip surface.

1. INTRODUCTION

An attempt to study stable necks as described in the foregoing paper /1/ in some detail lead to the finding that a tip can oscillate as briefly mentioned elsewhere /2/. The surprising result stimulated us to study the tip oscillation phenomenon. This paper describes the experimental findings as well as a first model for its explanation.

THE TIP OSCILLATION EXPERIMENT

The experimental conditions for the appearance and demonstration of a tip oscillation are : (1) a small cone angle tip (< ~ 3°) ; (2) a relatively high temperature (~ 0.8 Tm < T < Tm ; Tm - melting point) and (3) an in situ observation or registration (video) of the tip /2/ /3/. The oscillations are visible in situ in the bright field (fig. 1) or in the dark field mode (TEM) (fig. 2) and sometimes also by SEM. These conditions are fulfilled at present only in the experiments with copper and gold tips.

Typical oscillation characteristics are : (1) the tip neck diameter oscillates with an amplitude in the order of 300 Å (fig. 2) ; (2) the tip length oscillates...
with an amplitude in the order of 200 Å. The oscillation frequency is in the order of 0.3 Hertz, but fairly irregular. A tip neck oscillation is not a rare event but a frequently found phenomenon provided the tip neck is fine and the graphitized surface layer is not too thick (\( \sim 10^3 \) Å). All the oscillations are better visible on video films than on micrographs as in fig. 2.

We have found tip oscillations so far on Cu and Au tips, but such oscillations exist probably also on tips of other metals if adequate experimental conditions are introduced.

**Fig. 2 - Four phases of a Cu tip oscillation period. TEM dark field mode. Bright appears the graphitized layer. Minimum neck diameter \(- 200 \) Å.**

**EXPLANATION OF THE TIP OSCILLATIONS**

Is it possible to understand these tip oscillations? A first attempt of such an explanation is described in the following. Fig. 3a shows schematically the initial phase of an oscillation period. A solid metal drop is separated from the new metallic tip end but still held by a graphitized layer /1/. The impact of the microscope electrons charges the more or less isolated metal drop but not the tip which is on earth potential (fig. 3b). The charge of the drop leads to an electrostatic force between drop and tip. This force seems to press the hollow layer part in such a way, that the neck diameter as well as the total tip
The model to explain the tip oscillations.

**Fig. 3a, b, c, d:**

- **a)** Initial phase (after drop formation)
  - Growth of field protrusions (Taylor cone?)
  - Tip-drop distance (maximum compression)

- **b)** Change of phase by electron impact
  - Initial phase (after drop formation)
  - Tip on earth potential
  - Electrons cause:
    1. A potential difference
    2. A drop temperature increase
  - Elastic layer deformation
  - Electrostatic force and drop displacement

- **c)** Phase of minimum neck diameter before a field discharge
  - Field electron and field ion current between tip and drop
  - Minimum tip-drop distance (maximum compression)

- **d)** Phase after field discharge; disappearance of the electrostatic force; the elastic counter-force reproduces phase (a).
length decreases (fig. 3b). The charge creates also an electric field between drop and tip. This field should increase to values in the order of that of field emission ($10^7$ to $10^8$ V/cm) when the drop potential arrives values in the order of $10^2$ to $10^3$ volt. The energy of the impinging electrons ($30$ kV, $100$ kV and $3$ MV in our experiments) is by far sufficient to create such potentials. Continuous electron impact should lead to a force increase or a further decrease of the neck diameter and the drop-tip distance. The appearance of a drop protrusion which is typical for a field protrusion of a field emitter (fig. 2 and 3) (perhaps a Taylor cone?) may be a proof of the presence of the high field strength in this phase. This field strength may cause also a stable field emission current between drop and tip. The continuously increasing field strength should cause another known effect: the change of a stable field emission into an unstable emission or a sudden great increase of the current. This should occur between phase c and d of fig. 3. A difference to the known instability must be a limitation of the current due to the limited charge of the drop. Such drop discharge must lead to a sudden disappearance of the electrostatic force so that the counter force of the elastically deformed layer (fig. 3c and 3d) should push the drop back to its initial positions. When the initial phase (fig. 3a) is reestablished, the system is ready for another oscillation period, etc.

It is clear that such a model needs to be confirmed, completed and perhaps corrected. Nevertheless the presented explanation seems to be the only one which is not in contradiction with one of the experimental results obtained so far.

CONCLUSIONS

(1) At the end of metal tips visualized by electron microscopy a formation of stable necks and solid drops is found. Such tip ends become unstable or oscillate at higher temperatures. Oscillating is the neck diameter as well as the total tip length.
(2) The oscillation is explainable by an electrostatic force produced by the impinging microscope electrons. This force leads to a drop displacement until an increasing field emission leads to a drop discharge combined with a decrease of the electrostatic force so that an elastic counterforce brings the drop back to its initial position, etc.

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REFERENCES


/2/ M. Drechsler, S. Ramdani and A. Maas : paper accepted by Surface Science