STUDY OF EMISSION PROPERTIES OF TUNGSTEN SINGLE CRYSTAL WITH CRYSTALLOGRAPHIC ORIENTATION

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Abstract

The aim of the work was to determine the emission pattern of tungsten single crystal with crystallographic orientation of the growth axis <310> prepared by the electron beam zone melting applying the „floating zone“ method at the Department of Non-ferrous metals, refining and recycling VŠB-Technical University Ostrava as a new type of prospective material for production of electron emitters. For this purpose, first of all, we had to prepare a crystal nucleus of the corresponding orientation applying our own technology. The orientation of the axis of the obtained tungsten single crystal was checked by the classical X-ray Laue method of back reflection followed by an evaluation. The testing of emission properties itself was carried out in the firm DELONG INSTRUMENTS a.s. Brno in terms of direct co-operation, where an emitter was made of the given tungsten single crystal sample. The obtained emission pattern was excellent and it can be stated that the given tungsten single crystal meets all requirements on production of emitters for electron microscopy.

1 INTRODUCTION

In the 1960th conventional heated cathodes in scanning microscopes were replaced by electron-beam guns exploiting field emission called „field emission guns“. This enabled to achieve high resolution in electron microscopes and other devices that work with electron beams. A comprehensive survey of properties, applications and production of „field emission“ cathodes can be found in numerous publications [1-4].

One of the main emitter characteristics is the electron work function $A$, which is the energy needed for surmounting the electron bindings in the substance structure and it is in particular given by the material internal structure (crystalline structure and electron structure). If a given material (emitter) is placed in a strong electric field, the potential barrier, the height of which represents the work function, reduces. In such a situation electron tunnelling may happen (with the lowest work function) through the contracted potential barrier and thus the emission itself. The resulting flow of electrons from the material surface due to the strong electric field is called „field emission“. Emission properties are also influenced considerably by the condition of the emitter surface. Metals with single crystal structure are characterized by substantial anisotropy of emission properties in different crystallographic directions. This anisotropy is explained by different density of atomic occupation of different crystallographic planes forming the metal crystal surface.

The aim of the work was to judge emission properties (obtaining the emission pattern) of tungsten single crystal with the axis of growth crystallographic orientation <310>, which is a prospective material for production of emitters for electro-vacuum technology. This specimen of single crystal was prepared by the electron beam zone melting applying the „floating zone“ method in the vacuum $10^{-4}$ Pa at the Department of Non-ferrous metals, refining and recycling VŠB-Technical University Ostrava.

The initial material was tungsten in the form of sticks diameter 4 mm prepared by classical procedures of powder metallurgy and provided by the firm Plansee Metall GmbH with chemical attestation. In the first stage a single crystal nucleus of the required orientation was prepared applying our own technology including a
special holder placed in a goniometric head enabling to turn the specimen into a required position. Then the specimen was truncated and the holder with the nucleus was placed straight into the electron beam zone melting furnace where another tungsten rod, the total length 30 cm, was welded to it. The following preparation of the tungsten single crystal <310> was executed by two passes of the molten zone, speed 3 mm/min. The specimen crystallographic orientation was checked by the X-ray Laue method of back reflection followed by the evaluation by the help of Greninger net.

2 EXPERIMENTAL

From the obtained tungsten single crystal <310> an emitter was cut out in the firm DELONG INSTRUMENTS a.s. Brno by an electronic cutter. A tip (for emission of electrons) of the radius about 100 nm was formed at the end of the emitter by electrochemical etching in NaOH solution so that a sufficiently great gradient of electrostatic field was created by the negative potential (-3 kV) contact and thus an emission of electrons. Fig. 1 documents an insulator with a supporting tungsten hairpin (polycrystalline tungsten wire, diameter 0.1 mm) which serves as a holder of the emitter itself at projection and simultaneously the emitter can be heated at the current passage through the hairpin in order to clean and heat form the emitting facets and interface. The emitter itself was welded on the tip of this hairpin.

![Fig. 1 The representation of insulator with the supporting tungsten hairpin on the tip of which the emitter itself was welded.](image1)

![Fig. 2 The detail of the welded emitter, which was cut out of the tungsten single crystal by an electronic cutter.](image2)

![Fig. 3 The detail of the emission tip with the axis in the direction [310]](image3)

A detail of the emitter weld acquired by electron scanning microscope is shown in fig. 2. Fig. 3 made by electron scanning microscope shows a detail of the emission tip itself, the axis of which in the direction [310] and the tip were the place from which the emission of electrons took place in the angles corresponding to individual crystallographic directions.

Fig.4 represents a cross-section of the vacuum apparatus for electron projection in which the testing of the emitter from the tungsten single crystal with the orientation <310> was performed. The emitter was placed by itself opposite the transparent screen (scintillator) in which the emission pattern observed through the
vacuum loop-hole arose. The emission of electrons from the tip was created by a simple touch of the negative potential of about 3 kV on the emission tip itself at room temperature. Electrons are only extracted from the tungsten surface thanks to a high gradient of electrostatic field, which is the consequence of a small radius of the emission tip connected to the negative potential 3 kV.

3 DISCUSSION

The obtained electron emission pattern from the emitter made of the tungsten single crystal with the

![Fig. 4](image)

**Fig. 4** The cross section of the vacuum apparatus for electron projection in which the experiment itself was performed.

![Fig. 5](image)

**Fig. 5** The evaluated Laue diffraction pattern of the tungsten single crystal with the orientation <310>.
crystallographic orientation <310> was high quality and corresponds entirely to the X-ray projection – see fig.5. It is evident from fig.5 that intensive emission from the tip terminated by the (310) flat can be observed. The flats formed by the planes (100), (110) and (211) show minimum emissions with respect to the great work function of electrons – see table 1 [5]. More intensive edges of these flats arise due to the electric field greater gradient in these spots.

![Image](image_url)

**Fig. 6** The emission pattern from the cathode made of the tungsten single crystal with the orientation <310>.

**Table 1** The values of work function of electrons for selected planes in the tungsten single crystal

<table>
<thead>
<tr>
<th>Plane</th>
<th>(310)</th>
<th>(111)</th>
<th>(100)</th>
<th>(211)</th>
<th>(110)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work function of electrons $A$ [eV]</td>
<td>4.2</td>
<td>4.4</td>
<td>4.6</td>
<td>4.9</td>
<td>5.3</td>
</tr>
</tbody>
</table>

4 CONCLUSION

It can be stated on the base of the results achieved that the tungsten single crystal with the axis of growth crystallographic orientation <310> prepared by the electron beam zone melting meets all requirements on the production of emitters for electron microscopy. This type of emitters is characterized by a high value of brightness and high coherence. Electron-optical devices utilizing self-emission sources of electrons described above achieve distinctively better optical parameters, such as e.g. resolution and contrast. It is obvious that it concerns the development of a very prospective technology.

ACKNOWLEDGEMENT

*This work was solved in the frame of the postdoctoral grant project GA ČR č.106/06/P288 “Preparation and study of characteristic properties of single crystals of binary and ternary alloys on the base of tungsten and molybdenum” and in the frame of the research project MSM 6198910013 „Processes of preparation and properties of highly pure and structural defined materials“.*
REFERENCES


