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NOTE

The STM analysis of a silver mirror surface

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In this work, the structure of a silver mirror surface was examined by the STM technique. It was shown that the structural characteristics which enable a high degree of mirror reflection from this surface, which is very close to the ideal reflectivity of silver, are: flat and mutually parallel parts of the surface which are smooth on the atomic level, and distances between adjacent flat parts which state several atomic diameters.

Keywords: silver mirror, STM technique.

Electroplating processes are widely used in many branches of industry, the most important of which are: the automobile industries, building and construction industries and electrical and electronics industries.

The most electrodeposited metals are: zinc, nickel, chromium and copper. Nickel is mainly used for decorative purposes in high-value products, such as motorcycles, bicycles and furniture.

Often, multiple layers of nickel or copper-nickel-chromium combinations are used in the automotive industry. Zinc is usually used for corrosion protection. Copper is widely used in the manufacture of microelectronic components.

In order for metal coatings to be used for decorative purposes, it is necessary that their surfaces be smooth and bright. For this reason, the terms "mirror bright", "semi bright", and "high bright" are often used when considering electrodeposition processes. However, there are no precise definitions of these terms. The brightness of a surface is usually associated with the reflectivity of the surface, *i.e.*, by the amount of light specularly reflected off the surface, *i.e.*, at an angle equal and opposite to that of the incidence light with respect to the normal to the geometrical surface. A more precise definition, not involving the actual reflectivity of the surface, would be in terms of the ratio between specularly and diffusely reflected light.[1,2] Also, the ratio of specular to total reflectivity can be used for an estimation of the brightness of a surface.[3]

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Structural details which must be fulfilled in order for light from metal surfaces to be to a high degree specularly reflected have not been systematized yet. One of the reasons was, among other things, the lack of a suitable technique for the examination of the structure of bright metal surfaces. However, over the last few years the techniques of scanning tunnelling microscopy (STM) and atomic force microscopy (AFM) have proven to be very valuable techniques for the examination of metal deposits.[4,5] The advantage of these techniques with respect to classical techniques for the examination of the structure of metal surfaces (for example, the technique of scanning electron microscopy (SEM)) is the high resolution which is attainable using them. They enable a precise analysis of the topography of a metal surface, *i.e.*, they enable the examination of the submicrotopography of metal surfaces. Also, the digital images obtained by these techniques can easily be analyzed by powerful software packages.

In the past several years, the structures of bright metal surfaces have been the subject of several investigations in our laboratory.[6–9] In order to classify the obtained structures according to the degree of mirror reflection, the necessity to examine a mirror, which would function as the reference standard for the comparison of different bright metal surfaces, became obvious. For this reason, in this work, STM analysis of a silver mirror surface was undertaken.

Silver was chemically deposited onto a glass by the silver mirror reaction.[10] The reflection was determined using a Reflectance Spectrophotometer BECKMAN UV 5240, *i.e.*, the specimen was illuminated by a beam whose axis was at an angle not exceeding 10º from the normal to the specimen [normal/total (abbreviation, 0/t): nor-

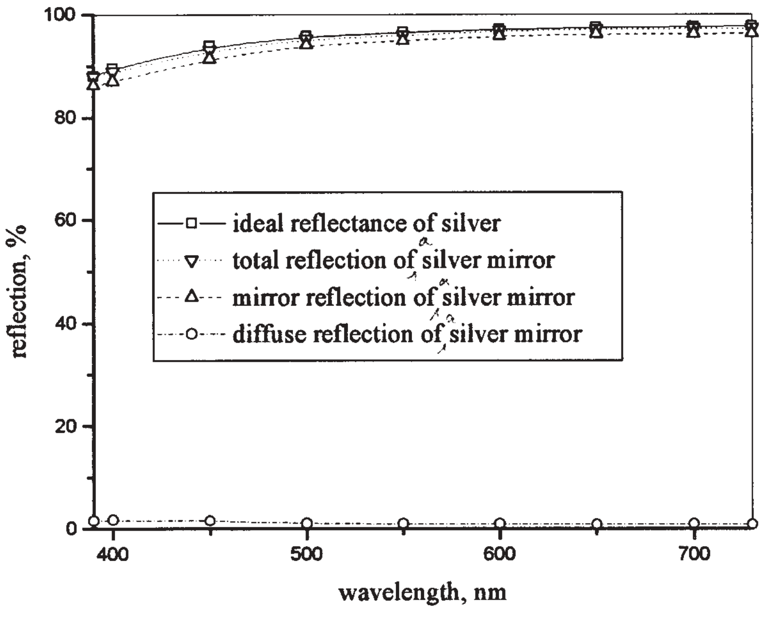

Fig. 1. The dependence of the degrees of reflection on the visible light wavelength for the ideal reflectivity of silver (□), the total ∇), mirror (Δ) and diffuse (o) reflection of a silver mirror.

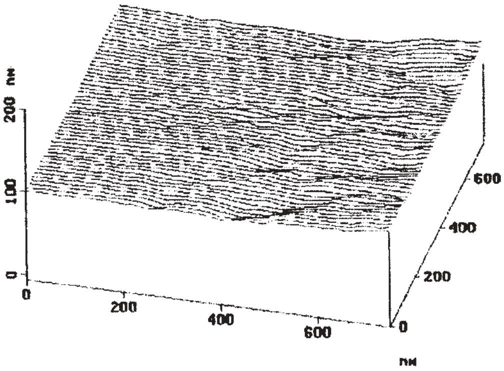

Fig. 2. 3D STM image of a silver mirror surface. Scan size 700×700 nm^2.

mal/diffuse (abbreviation, 0/d)]. The reflected flux was collected by means of an integrating sphere. This type of Reflectance Spectrophotometer gives the dependences of the total reflection and the diffuse reflection as a function of wavelength. The difference between the total reflection and the diffuse reflection is the mirror reflection, which is a parameter for the estimation of the brightness of a metal surface.[11]

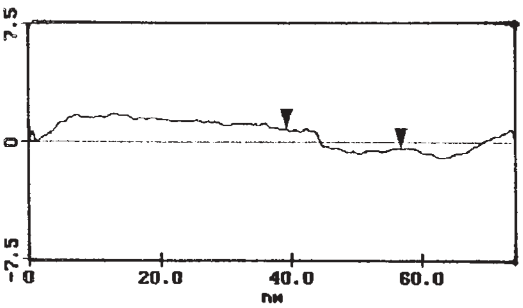

Fig. 3. Line section analysis of a portion of the STM surface shown in Fig. 2. The distance between the markers represents 1.246 nm.

The topography of the surface was determined by a STM NanoScope III in air. The STM images were obtained in the constant current mode using a W tip electrochemically sharpened in 1 M KOH solution. The bias voltage ranged from 16.2 to 17.5 mV and the tip current from 7.8 to 9.0 nA for a silver mirror.

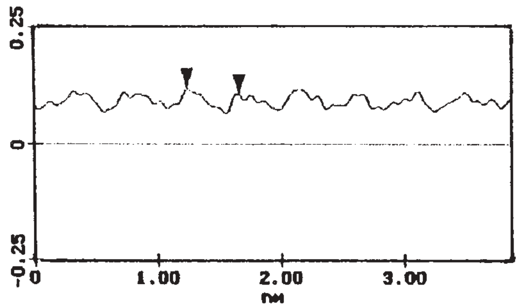

Fig. 4. Line section analysis of the flat part of the surface shown in Fig. 2.

The ideal (theoretical) reflectivity of silver[12] and the degrees of total, mirror and diffuse reflection as a function of visible light wavelength for a silver mirror surface are given in Fig. 1. Figure 1 shows clearly that the reflection of light from this surface is mostly mirror reflection and the degree of diffuse reflection is very small (up to 2 %).

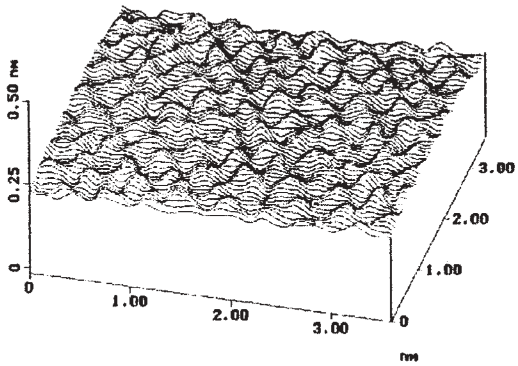

Fig. 5. 3D STM image of a silver mirror surface. Scan size 3.50 × 3.50 nm^2.

The degree of mirror reflection from a silver mirror is also very close to the ideal reflectivity of silver.

The 3D (three-dimensional) STM image (700 ×700) nm^2 of silver mirror surface is shown in Fig. 2, from which it can be seen that the surface of a silver mirror is very smooth. The line section analysis of this surface is shown in Fig. 3, which shows that this surface consisted of relatively flat and mutually parallel parts. The STM software measurements showed that distances between adjacent relatively flat parts were several atomic diameters of silver. For the part of the surface shown in Fig. 3, the distance between the markers represents 1.246 nm. The atomic diameter of silver is 0.288 nm,[13] and consequently, this distance is equvalent to 4.3 atomic diameters of silver.

The line section analysis of a reltively flat part of the surface is shown in Fig. 4. It was shown by the STM software measurements that the roughness of the flat part of the surface is less than the atomic diameter of silver, *i.e.*, the flat parts are smooth on the atomic level. The atomic arrangement of a flat part of a surface is shown in Fig. 5.

Finally, the reflection of light from the silver mirror surface is mostly mirror reflection and this reflection is very close to the ideal reflectivity of silver. The structural characteristics of this surface which enable a high degree of mirror reflection are that the surface should have flat and mutually parallel parts which are smooth on the atomic level, with adjacent flat parts being separated by several atomic diameters of silver.

И З В О Д

STM АНАЛИЗА ПОВРШИНЕ СРЕБРНОГ ОГЛЕДАЛА

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STM техником је испитана структура површине сребрног огледала. Показано је да су структурне карактеристике које су омогућиле висок степен огледалске рефлексије који је био веома близак идеалној рефлексивности сребра: равни и међусобно паралелни делови површине који су глатки на атомском нивоу, и растојања између суседних равних делова која износе неколико атомских пречника.

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