



A low-temperature gold coating of the dielectric surfaces employing phosphine gas as a reducing agent



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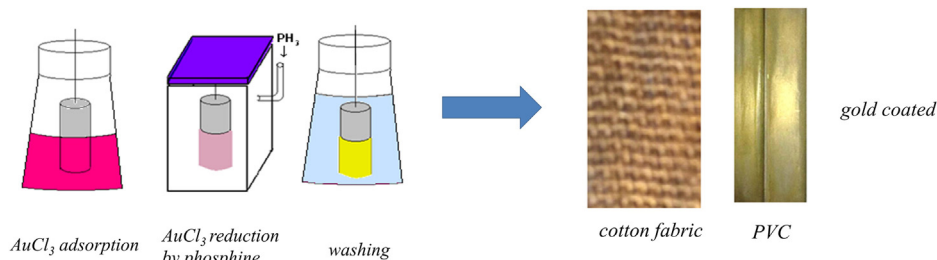
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HIGHLIGHTS

- A new low temperature technique to prepare gold films on the dielectric surfaces is developed.
- Gold-copper phosphide coating is obtained by adding copper chloride.
- Thickness of the coating depends on the concentration of the gold chloride solution.
- Diamond particles are incorporated into the gold coating to improve surface and mechanical properties of the coating.

GRAPHICAL ABSTRACT



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ABSTRACT

The technology of applying the gold film on the dielectric surface, based on the low-temperature reduction of the superficial sorption layer of gold chloride by phosphine gas, was developed. The sorption layer was obtained by immersing the product in a solution of gold chloride. The thickness of the coating depended on the concentration of the gold chloride solution. Adding copper chloride a film of gold-copper phosphide can be obtained. To give functional properties to the film, non-metallic particles were incorporated in the film. So when diamond particles sprayed on the wetted gold chloride surface, a gold-diamond coating was obtained containing 4.25% of diamond.

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1. Introduction

Gold dielectric coatings are widely used in industries. Gold coatings have various functions such as [1–3]: protection from corrosion; catalytical activity; bactericidal ability; high electrical and thermal conductivity, low and stable contact resistance over time; necessary requirements for solderability; the ability to reflect infrared rays; use for decoration.

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Applications of gold coatings depend on physico-chemical properties of this metal.

Gold has a very high resistance to corrosion. Therefore, since ancient times used as a method of corrosion protection [4,5]. Although such a coating base metals (in this case, the underlayer) has disadvantages (coating softness, high potential at point corrosion), it is common due to the fact that increases the lifetime of various electronic devices.

As per electrical and thermal conductivity gold is second only to silver and copper, which resulted in the application of gold coatings in the chemical industry, electronics and instrumentation [6,7]. In Electronics gold is used to cover various kinds of contacts, gold with nickel underlayer allows multiple resolderings cycles and ensures solderability for 6 months [8].

Almost 100% of gold's ability to reflect infrared rays allows its use in the glass industry, for metal window panes of buildings [3,8].

Gold is also known for its catalytic properties. Gold catalysts have been used for the oxidation of alcohols, aldehydes and carbohydrates [9,10], therefore methods of applying gold particles at various carriers have been developed. For example, use of gold as a catalyst in automobile fuel system is promising [9]. Bactericidal activity of gold (Cu) is 2–3 times lower than silver (Ag), however, the bimetallic composition Ag/Au=5 has the best bactericidal action, where a small addition of silver enhances the gold activity [11].

Requirements for gold coatings have led to the development of a number of gold-plating techniques. Conventionally, they can be divided into electrochemical (galvanic), chemical and physical methods. The most common method is a galvanic technique based on applying gold coating from the solutions on the basis of a complex salt, potassium dicyanoaurate(I), $\text{KAu}(\text{CN})_2$ [4]. Electrolytes containing various additive elements, arsenic [12,13], indium [14] and alkylsulfonic salts and acids [15] have been developed for gold coatings. The electroplating method allows also to obtain dense fine-grained semi-gloss bright gold coating containing dispersed diamond additives, which gives the coating high wear resistance, and retains increased electrical and technological properties [16]. The inclusion of ultrafine gold-silica gel or nanodiamond particles [5,8,17] on gold containing gel coating provides a nonporous, corrosion resistance, greater hardness and wear resistance as compared with coatings obtained using the method of precipitation tank.

The disadvantage of galvanic technique is the use of toxic cyanide compounds, the impossibility of coating on the inner surface and the need for pre-metallization. In chemical coating process cyanide, ferrocyanide, chloroauric electrolytes containing as reducing agents such as dimethylboran, hydrazine sulfate, sodium hypophosphite, citrate or tartaric acid [18,19] are used. Using chemical methods gold is deposited on copper, nickel and silver. When coating dielectric materials it is necessarily first to apply these metals to the surfaces.

One of the types of chemical plating is an immersion (contact) plating method [6,7,20,21]. This method is used for coating silver, copper and nickel. It provides quality coverage of complex parts or inner tubes cavities. The method has a limit on the coating thickness (less than 0.2 μm). Furthermore, when dielectric surfaces are employed, it requires a nickel pre-coating, which creates a multi-step process.

The physical gold coating methods [22–24] include vapor deposition, thermal evaporation based on organic compounds of gold and gold vapor condensation on the surface of a product or ion beam or laser sputtering of gold particles. The advantage of physical methods of coatings is the possibility of applying gold directly on the surface of the product, while the disadvantage is the need for expensive and complex installations.

From literature it is evident that there is still a need for low temperature gold coating methods using gaseous reducing agents. The basis of our proposed method is to use a gaseous phosphine as a

reducing agent. Earlier we employed this reducing agent for coating technologies on metal and dielectric materials such as copper-phosphorous and silver films [25–28].

The process, that is described in this paper, is based on obtaining gold coatings employing low temperature gaseous reaction between phosphine and gold chloride. Employing this gaseous reducing agent allows preparing porous coatings on dielectric materials and composite surfaces. Coatings are formed on both inner and outer surface of the treated material employing phosphine as a reducing agent. This helps increase of coating adhesion to fabrics and porous materials.

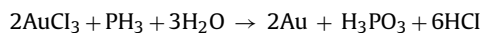
Use of water soluble reducing agents such as vitamin C has some difficulties associated with reduction inside pores of the dielectric materials, this can lead to creation of non-homogeneous coating. Use of other reducing agents such as gaseous hydrogen requires high temperatures and in this process it is not possible to use aqueous gold solutions.

Our described process is robust, easy to scale-up and to employ in industry for various applications. Since we did not target biomedical application of the coatings, toxicity is not an issue in our study. Moreover, in our work we employed a method that removes residues of unreacted phosphine.

In this paper, a low-temperature coating technique using gaseous phosphine is presented for coating of different surfaces. The obtained coatings were characterized employing electron microscopy, SEM techniques.

2. Materials and methods

A reaction of phosphine with gold chloride is outlined below. The special feature of this reaction is that the product of the reaction is pure gold without phosphides [29].



Separate stages of the gold coating process is shown in Fig. 1.

To create a sorption layer it is necessary to create wettability of the surface of the product. For this purpose, preliminary procedures of etching and degreasing were carried out. We used the method recommended in the literature [18]. For nonmetallic materials, having a porosity or a rough surface, the etching step is optional.

Prepared samples (Fig. 1a) were immersed in a gold chloride solution for 1–3 min. This produced a sorption layer (Fig. 1b) on the sample surface.

It should be noted that the concentration of gold chloride in the solution used to create a sorptive layer affects the thickness of the resulting gold film. Thus at a concentration of 10 g/L to 150 g/L film thickness (for flat samples) changes from 0.03 μm to 0.5 μm .

The product was then dried at 25 °C to create a wet film of gold chloride with sufficient permeability (Fig. 1c). Drying time was generally 50–60 min. Thus the dried product was placed in a sealed chamber and fed to gaseous phosphine until its absorption termination. Our techniques for producing phosphine and its use to produce surface films, as well as the determination of film thickness did not differ from those given in Refs. [27,28].

As a result of the reaction of gold chloride with phosphine a gold film was formed on the surface of the sample (Fig. 1d), which still contained reaction byproducts. After washing with water we obtained a sample (Fig. 1e) covered with a film of pure gold.

Gold coatings were created on the surface of cotton fabric and porous PVC materials. Samples were dipped for 3 min in a solution containing 100 g/L of gold chloride. Then by shaking the excess of gold chloride solution was removed. The sample was then dried at 25 °C for one hour.

The wet sample was placed in a sealed chamber where air was removed by purging with nitrogen. The camera was connected to

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