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Nanoscale Particles Enhanced Gold Plating

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Abstract. Using precious metals as plating materials is an effective measure to avoid failures of electrical contacts caused by fretting. When using precious metals, such as gold, one of the limitations to their lifetime is the wear resistance. In order to improve the wear resistance of gold plates, gold alloy is usually used.
Instead of alloying elements, nanoscale particles of metal oxides were used for the modification of plates in our investigation. Some of the nanoscale particles show considerable impact on the performance of plates for electrical contacts. This paper shows the first results and new challenges when using nanoscale particles for electroplating.

Introduction

Fretting is considered to be one of the major problems that affect the lifetime of electrical connectors. Different phenomena are related to fretting, such as fretting wear, fretting fatigue, fretting corrosion, insulating layer and oxides [1-3]. Among these phenomena corrosion, insulating layer and oxides are basically the direct cause of a major increase in contact resistance. Therefore using metals, which have little or no film-forming tendency, generally known as precious metals, as plating materials should be an effective measure to avoid failures caused by fretting. When using precious metals, one of the limitations to their lifetime is the wear resistance of the plating material. This has been observed by some authors [1, 2]. Gold is one of the most commonly used precious plating materials for high performance electrical contacts. Pure gold is very soft. In order to improve the wear resistance of gold plates, hard gold is usually used. The high degree of hardness is achieved by alloying elements such as cobalt, iron or nickel. However, the effect of alloying elements is limited by the galvanic process and other surface properties, which are also required for electric contacts.
In this paper a new way of the modification of gold plates is investigated. Instead of alloying elements nanoscale particles, mostly metal oxides, were used for the modification of plates. The reason for using nanoscale particles is based on the fact that the hardness of the pure gold is about HV 70 and the hardness of the hard gold is about HV 170 [3]. The hardness of nanoscale particles of metal oxides ranges from HV 700 to 2300 [4]. It is well known from the tribology study that in general hard materials are more wear resistant than soft materials, provided other characteristics of the materials are the same [2].

Experimental

For the wear and fretting corrosion tests an apparatus is used which enables a small and precise displacement of fretting motion at the contact interface. A piezoelectrical actuator moving forwards and backwards generates the relative motion between the contacts. The wipe is 50 µm and the duration of a cycle is1 s. The contact force is provided with a dead load. The normal force was 4N. The contacts are wired for a four-wire resistance measurement. A computer controls the data acquisition system.

A transmission electron microscope (TEM) combined with an image processing program was used for characterization of nanoscale particles powder. An Ultrafine Particle Analyzer (UPA), which incorporated the Controlled Reference Method (CRM) in a dynamic light scattering instrument, was used to determine the particle size distribution in electrolytes. The wear of the contact area was measured after the wear test with a confocal laser scanning microscope (CLSM), which measured the surface topography with a precision of up to 10 nm. A scanning electron microscope (SEM) with a Focused Ion Beam System (FIB) and an energy-dispersive X-ray spectroscopy (EDX), an X-Ray fluorescence spectrometer and an optical microscope were also used for the material and surface analysis of the gold plating.
The contact springs were stamped. The base metal used was phosphor bronze (CuSn). The coating systems tested in this study were platings with different nanoscale particles modified gold as over plate with a under plate (barrier layer) of nickel, which prevents the diffusion between gold and base material. The nanoscale particles used for the investigation were metal oxides. The thickness of gold was between 0.6 and 1 μm. The samples were all electroplated. The mating parts for each test were always coated with the same material.
The basic target of our investigation is to increase the lifetime of gold plated electrical contacts. Several criteria can be used to determine the lifetime. The number of cycles to the rapid increase of contact resistance was used as lifetime, since it has the strongest impact on the behavior of electrical contacts and it is closely related to the wear performance of gold plating.

Results and Discussion

Nanoscale particles of different particle size distributions were used for the investigation. Due to agglomeration, the particle size distribution in the electrolytes changed. Much bigger particles were observed in electrolytes (Fig. 1).

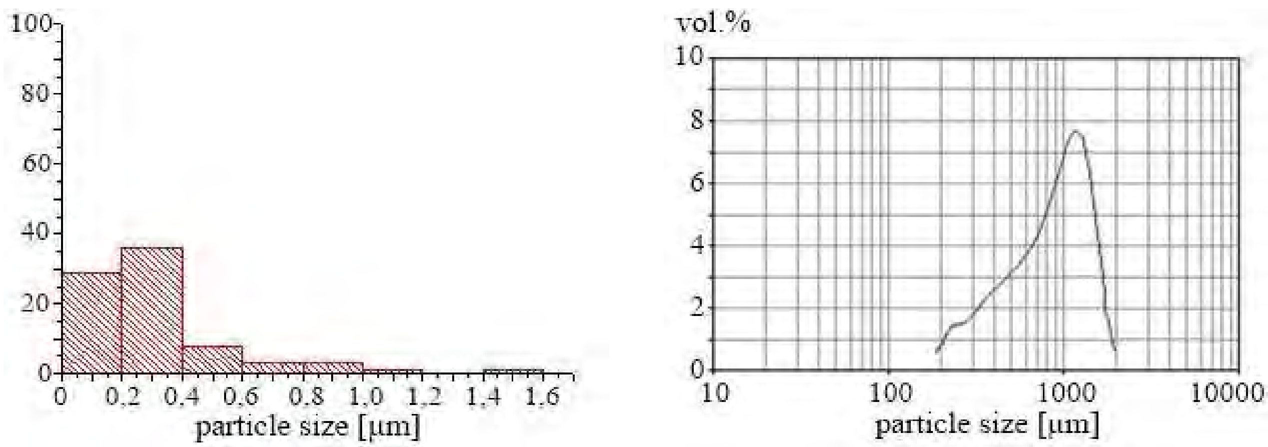

Fig. 1a: Particle size distribution of powder Fig. 1b: Particle size distribution in electrolyte

The particle size distribution in powder and in electrolytes with a TEM and an Ultrafine Particle Analyzer (UPA) was determined without any difficulty. Finding rapid and affordable methods for the determination of the particle size distribution and the amount of nanoscale particles in the gold plating turned out to be a big challenge. The X-Ray fluorescence spectrometer is only suitable for a rapid and rough control and classification of the thickness and some of the elements in the gold plating. In the first step the concentration of nanoscale particles in electrolytes was used as a process parameter in the electroplating. This revealed a good correlation between the concentration of nanoscale particles in electrolytes and the amount of nanoscale particles in the gold plating, Fig. 4. A further analysis showed that the amount of nanoscale particles in plates did not necessarily increase with the further increasing concentration of nanoscale particles in electrolytes. There is a saturation point.

The effect of different nanoscale particles on the lifetime of the electrical contacts in the wear and fretting corrosion tests in comparison to pure gold and hard gold, which are most widely used for high performance electric contacts, is shown in Fig. 3. The large range of lifetime is not due to a single runaway value. It is verified by numerous measurements. The large range of lifetime shows on the one hand the extensive potential of nanoscale particles modified gold platings, on the other hand the big number of parameters in the process chain from generation of nanoscale particles to the nanoscale particles modified gold platings, which yet have to be investigated and characterized.

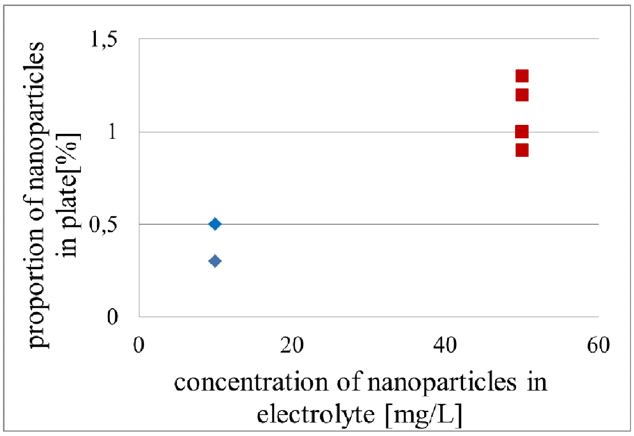

Fig. 2: Correlation between the amount of nanoscale particles in plates and in electrolytes

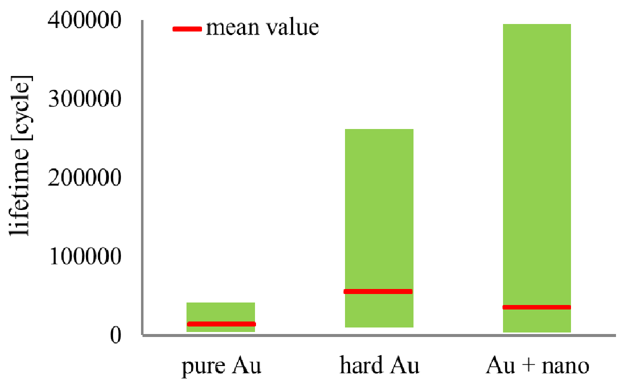

Fig. 3: Effect of nanoscale particles

The fact that the nanoscale particles modified plates show both an extraordinary long and short lifetime reveals that

- There is a large potential in terms of improving the lifetime of gold plates with nanoscale particles
- Putting nanoscale particles alone in the plates would not be sufficient. Other basic conditions have to be taken into account in order to achieve the desired effects.

Therefore, further analysis was conducted to study these basic conditions.

Concentration of Nanoscale Particles in Electrolytes

The samples were plated with electrolytes of different nanoscale particle concentration. From a certain concentration of nanoscale particles, samples with long lifetimes were observed, Fig. 4. A further increase of the concentration did not improve the performance of the plates, Fig. 5.

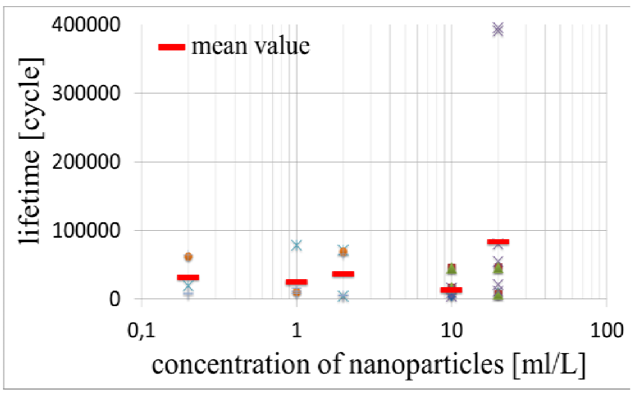

Fig. 4: Effect of concentration of nanoscale particles in electrolyte (particles in liquid)

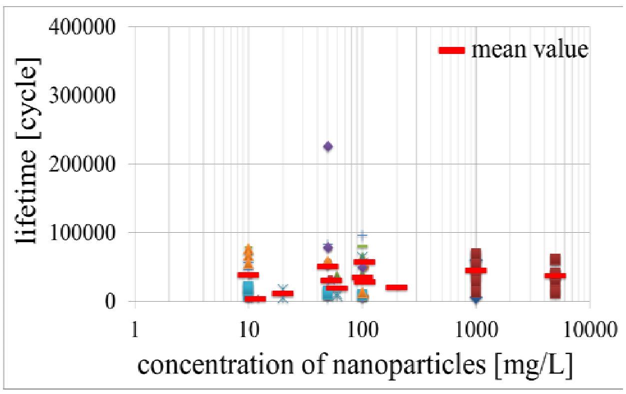

Fig. 5: Effect of concentration of nanoscale particles in electrolyte (particles as powder)

Effect of Peak Particle Size

The peak particle size is defined as the most frequently observed size of particles. It is therefore one of the characteristics of particles. Smaller particles are in general more difficult to produce than larger ones, but thought to be more strongly bound to the matrix material because of their larger specific surfaces (surface/volume). Fig. 6 shows that this does not necessarily lead to a long lifetime.

Nanoscale particles tend to agglomerate in electrolyte. Due to this the peak particle size measured in electrolytes is much larger than that in powder or water, Fig. 1a and 1b. Fig. 7 shows that if the agglomerates become too large, the average lifetime will be shortened. The limit seems to be the thickness of the gold plate.

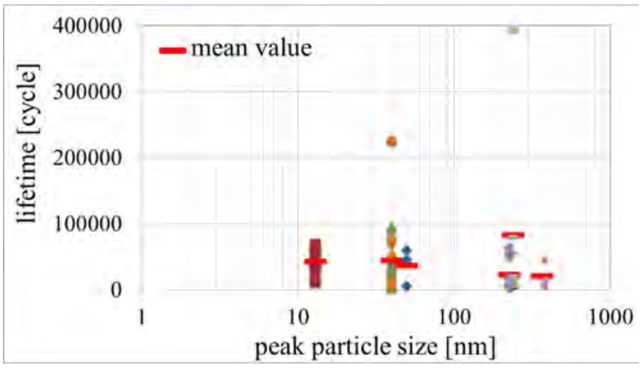

Fig. 6: Effect of peak particle size in powder

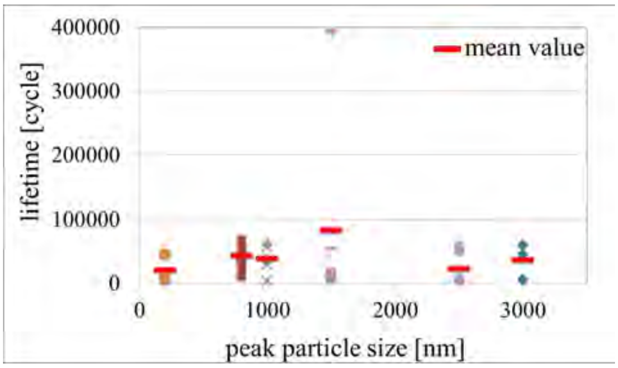

Fig. 7: Effect of peak particle size in electrolytes

Effect of the Thickness of Plates

Since the wear of plates is proportional to the cycles of motion, the number of cycles to the wear-out of the gold plate should be proportional to the thickness of the gold plate. Once the gold plate is worn out, the fretting corrosion of the under plate can commence. Therefore a dependence of lifetime on the thickness is expected. Our results showed that a minimum thickness of approximately 0.7 µm is required to achieve a long lifetime. However, thickness is a necessary but not sufficient condition for a long lifetime. Some samples with a thick plate also displayed a short lifetime.

Nickels under plates have a strong effect on the lifetime of electrical contacts. Samples with nickel under plates of 2.3 µm or less survived less than 10,000 cycles. All samples which survived an exceptionally large number of cycles of more than 200,000 have a nickel under plate of more than 3 µm.

The detailed analysis of a batch of nanoscale particles, which showed the longest average lifetime of about 120,000 cycles, confirmed the importance of nickel under plates. At first glance there is also a very large scattering of results. The thickness of the batch ranged from 0.85 to 1.2 µm. However the best samples had a thickness of 1 µm, Fig 8. Nevertheless the determining importance of nickel under plates could be clearly revealed, see Fig. 9. A similar phenomenon was also observed for hard gold plates. The reason for this phenomenon is the subsurface plastic deformation, which results in a deepening wear groove on the surface and the formation of buckles in the under plates. Above these buckles, localized surface wear occurs. With repeated cycling, exposure of under plate material eventually occurs at these sites. This occurrence is indicative of a local bulging of the underplate through the over plate. It was found that with sufficiently thick and stiff plates the mechanism could be eliminated [2]. Another reason for this phenomenon is the dependence of the under plate roughness on the thickness of under plates. It was found that the under plate roughness decreased with increasing thickness of up to 4 µm [5]. It should be mentioned at this point that the thickness of under plates is of course not the only determining parameter for the lifetime of electrical contacts with nanoscale particles modified gold plates. The amount of nanoscale particles in gold plates must be above a certain limit, which can be indirectly determined by the concentration of nanoscale particles in electrolytes.

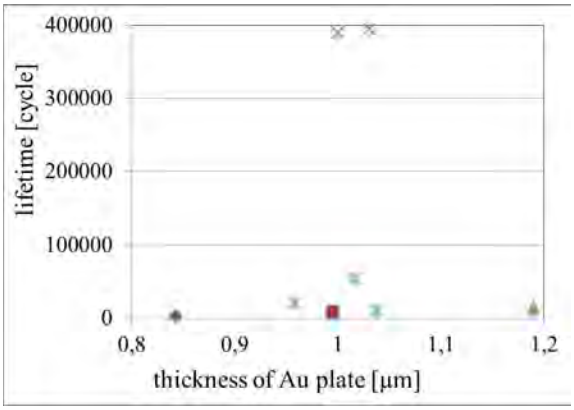

Fig. 8: The lifetime and the thickness of gold plates

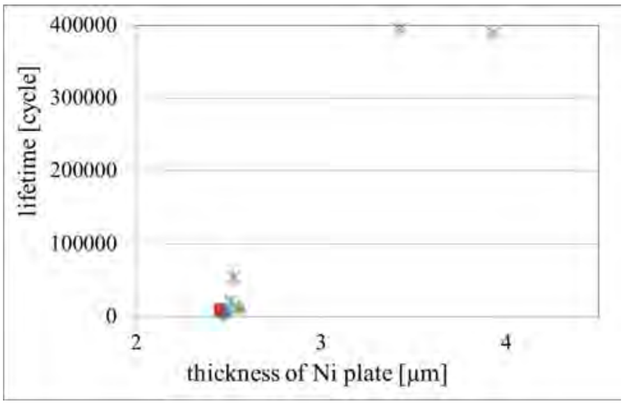

Fig. 9: Effect of thickness of nickel under plates

Topography of Gold Plates

Once the comparable amount of nanoparticles is in the gold plates, the surface topography is also an important factor. A spherical structured surface (Fig. 10) seemed to be more favorable than a smooth surface (Fig. 11). The nanoscale particles used, the thickness of gold plates and the amount of nanoscale particles in gold plates were identical in both cases. The thickness of gold plates was 1 µm and the proportion of nanoscale particles was 1%.

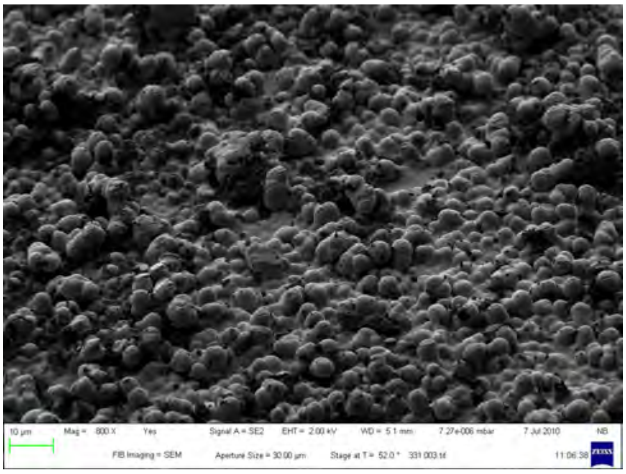

Fig. 10: Spherical structured surface (Lifetime: 400,000 cycles)

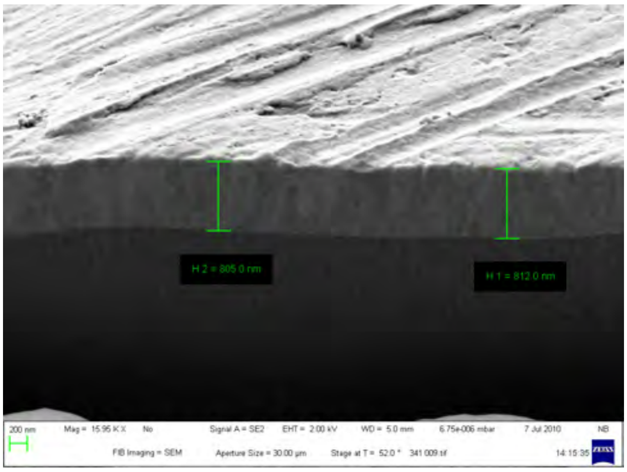

Fig. 11: Smooth surface (Lifetime: 55,000 cycles)

Wear resistance can be also analyzed with an energy dispersive X-ray spectroscopy (EDX). In case of a high wear resistance, the line scan of gold distribution shows a large amount of gold in the contact area after a long term test, Fig. 12a. In case of a poor wear resistance of gold plating, the line scan of gold distribution shows a much smaller amount of gold in the contact area after a long term test, Fig. 12b.

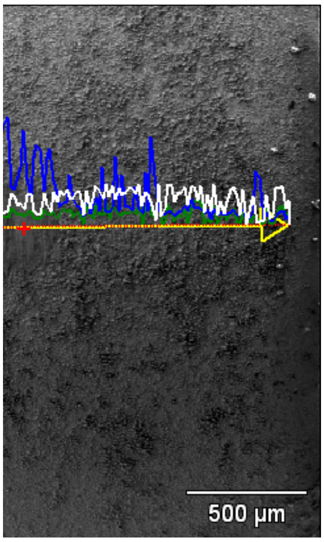

Fig. 12a: Line scans of gold in the contact area (white line). Due to the high wear resistance of gold plating, contact survives a more than 50,000-cycle test. Average depth of wear crater was 4 µm.

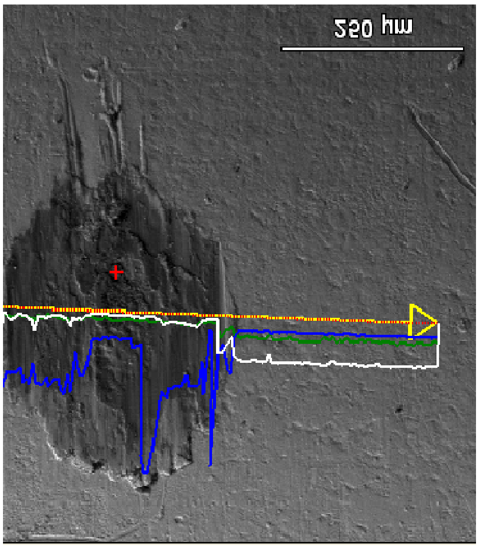

Fig. 12b: Line scans of gold in the contact area (white line). Due to the poor wear resistance, the gold plating is worn out after a 50,000-cycle test. Average depth of wear crater was 6 µm

Summary

Our investigation shows that the modification of the gold plating by means of nanoscale particles have a high potential to increase the wear resistance of gold plates and therefore leading to a large increase in the lifetime of electric contact. A combination of conditions has to be met, in order to reach the desired improvement in lifetime. Among these conditions, the amount of nanoparticles in gold plates, the thickness of both the gold plates and the nickel under plate and the topography of the gold plates are of most importance.
A lot of experiments are still to be done in order to find the optimal nanoscale particles for gold plating, to master the electroplating process and the production of nanoscale particles. The key issues of nanoscale particles are particle size distribution and particle distribution in gold plating.

Acknowledgment

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References

[1] M. Braunovic, V.V. Konchits, N.K. Myshkin, Electrical Contacts, pp. 214-230 (CRC Press, Boca Raton, 2007)
[2] M. Antler, Tribology of Electronic Connectors, in Electrical Contacts – Principles and Applications, pp. 332-364, P. Slade, Ed. (Marcell Dekker, New York, 1999)
[3] E. Vinaricky, Elektrische Kontakte, Werkstoffe und Anwendungen, pp. 153-154, (Springer, Berlin, 2002)
[4] G.L. Hornyak et al.: Introduction to Nanoscience & Nanotechnology, pp. 1098-1099 (CRC Press, Boca Raton, 2009)
[5] L. Shmidt: Optimierung der Oberflächen für elektrische Kontakte. Thesis at OWL UAS, Lemgo, pp. 21-22, 2010

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DOI References

[3] E. Vinaricky, Elektrische Kontakte, Werkstoffe und Anwendungen, pp.153-154, (Springer, Berlin, 2002).
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