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Gold-Zinc Oxide
A New Class of Hard Gold

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Abstract

In electronics applications gold has always been desired because it is chemically inert and has low electrical resistance. However, pure gold is soft and has unacceptable amounts of friction and wear. To reduce these problems hard gold is synthesized by alloying with Ni, Co or Fe which increases the hardness and wear. A limitation of hard gold coatings is the diffusion and segregation of non-noble alloying metals [illegible] electrical contact behavior. With advancements of co-deposition via physical vapor deposition (PVD) we have eliminated the electroplating material limitations and generated a new class of hard gold films. Using the Thermionics Triad E-beam evaporation system we have created thin films of gold alloyed with 0.1 – 2 vol% zinc oxide. The zinc oxide impedes grain growth thus making the gold stronger due to the Hall-Petch relationship. The film also displays enhanced thermal stability due to the ceramic characteristic of the ZnO, without the surface migration as seen in conventional non-noble alloyed hard gold. This study will show the long term stability of the alloy by thermal aging and the benefits this new class of hard gold brings to research and industry.

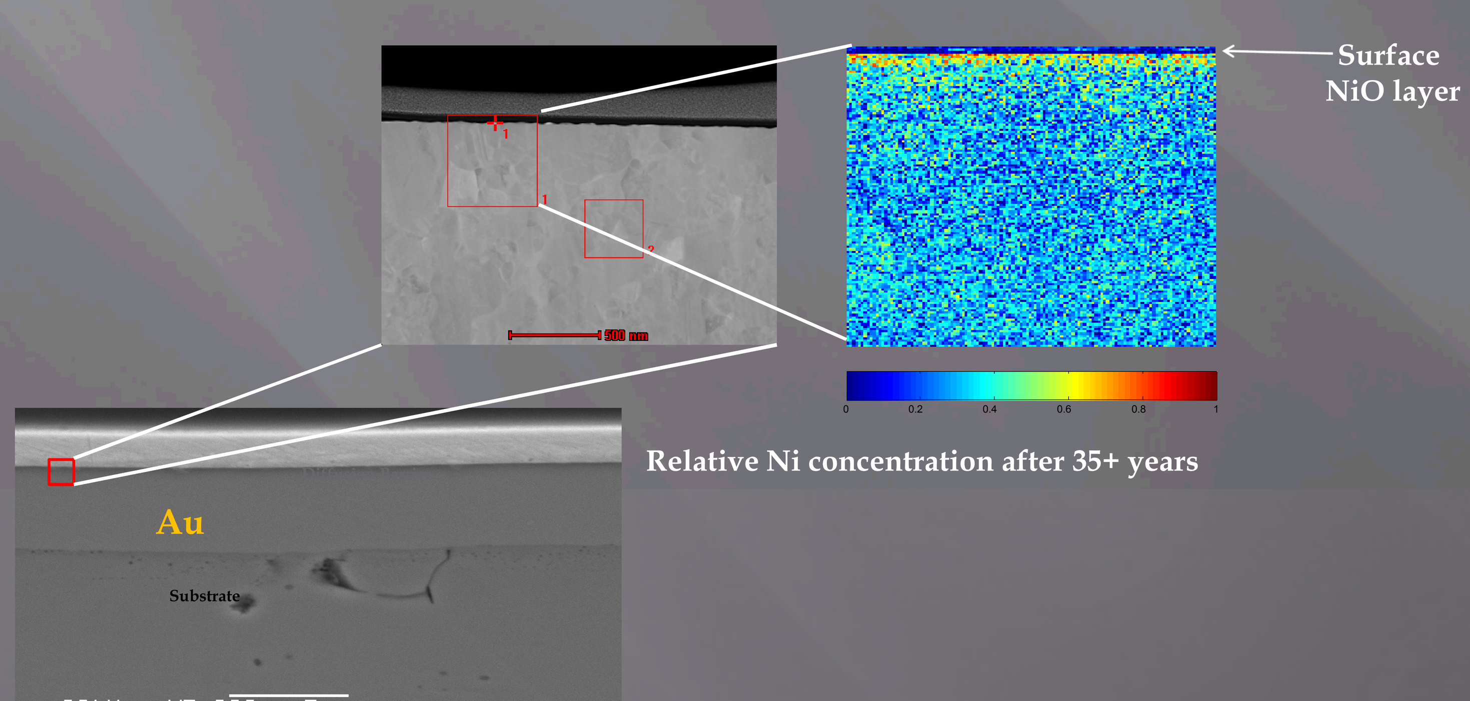
Uses for Hard Gold

Gold has always been a preferred material in the electronics industry because it is inert and has very low resistance. However pure gold is too soft causing it to wear too easily and it has too high friction. This is why hard gold is used. Co, Ni, or Fe are added to the the gold during electroplating, the dopants will fill the grain boundaries preventing grain growth. Because of the Hall-Petch relationship this will make the gold much harder and the resistance is still very low.

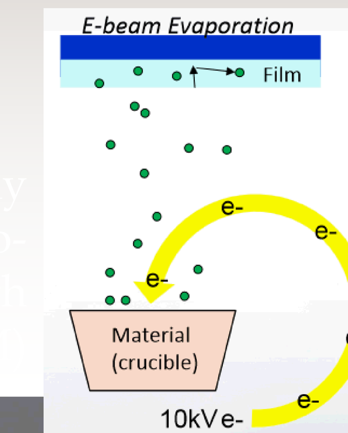
Traditional Hard Gold Limitations

Electroplated gold has some disadvantages. Gold is plated in a cyanide bath with modifiers of Pb, Cd, or Tl. This will increase costs to the manufacture because of environmental hazards and disposal fees.

Traditionally gold is hardened with Ni, Co, or Fe. All these materials will react with oxygen. This makes them susceptible to diffusion and segregation over time. Once the Ni, Co, or Fe makes it to the surface it will oxidize and form a nonconductive layer.



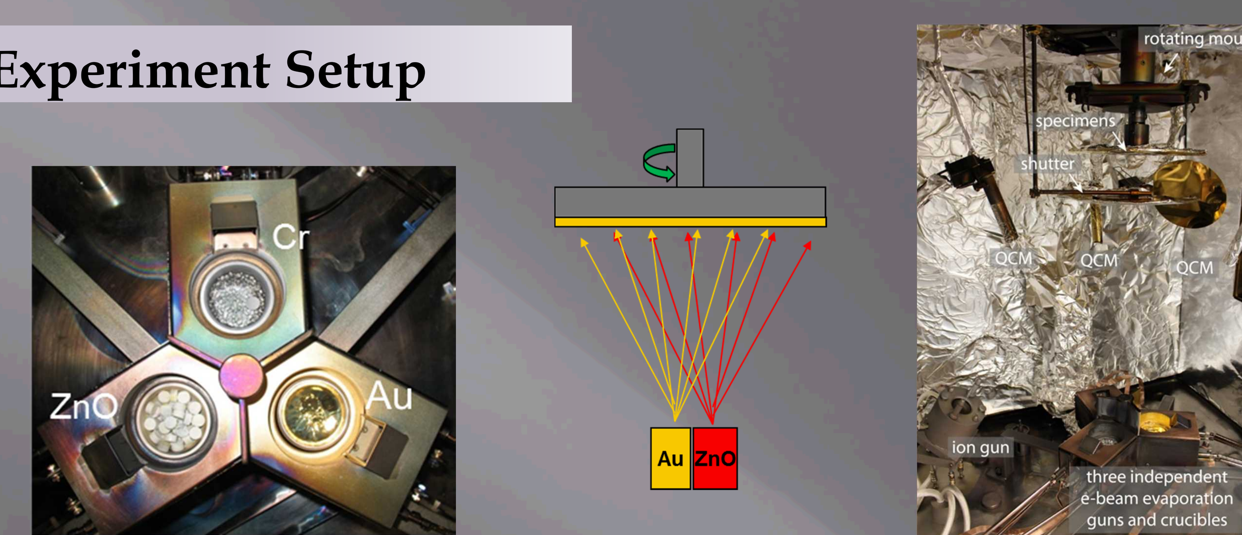
Electron Beam Deposition of Au-ZnO



Because E-beam evaporation can deposit virtually any material, this was the primary technique used to co-deposit ZnO and Au. Fine control is obtained with independent quartz crystal microbalances (QCM) which enable alloy compositions of 0.05 vol %.

The choice was made to use ZnO because it will not migrate to the surface like traditional hard gold dopants. Unlike many ceramics however, ZnO is a semiconductor. This should help keep the electrical resistance low while hardening the gold.

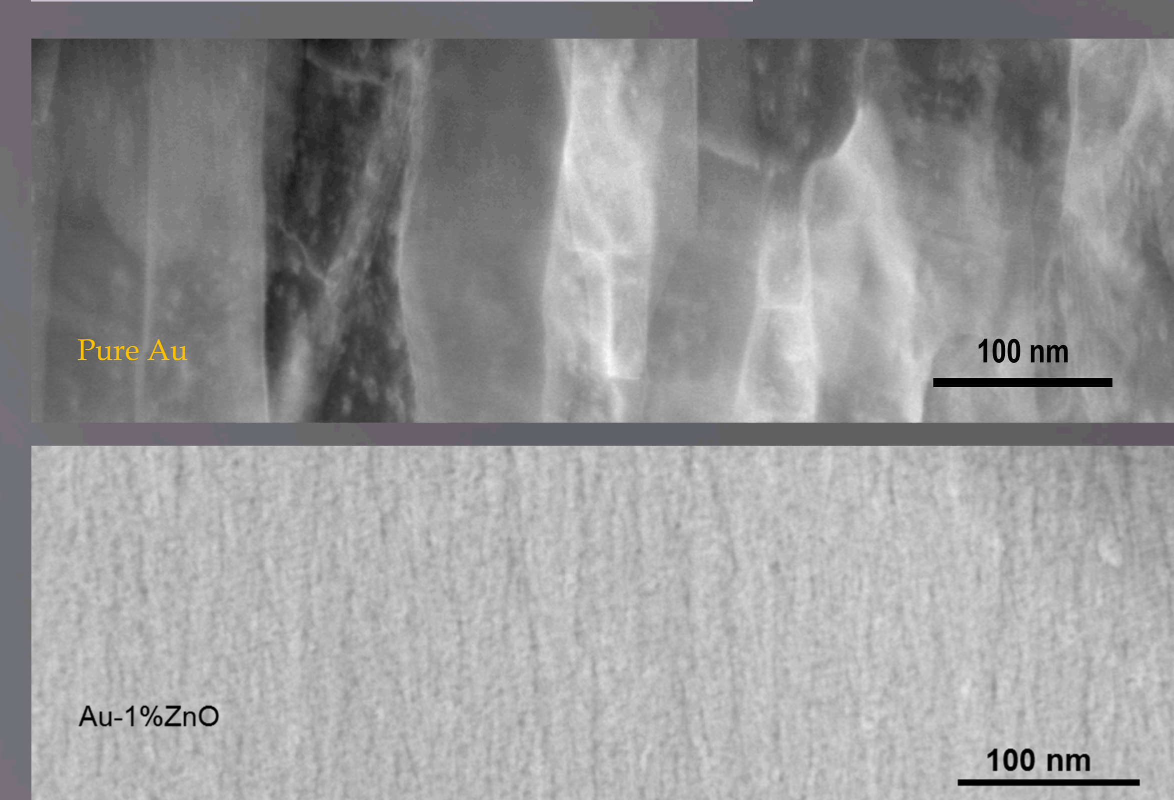
Experiment Setup

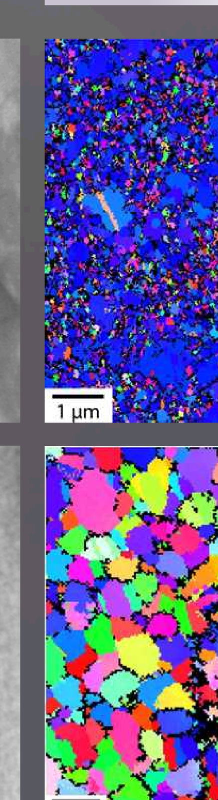


- Using Thermionics Triad e-beam guns, we have the ability to deposit up to three materials at the same time
- Substrates are rotated allowing better uniformity
- Three QCMs with line of sight shields used for independent rate control
- Shutters are used only over the parts to achieve appropriate Au-ZnO rates
- All runs in this experimental study were 2 microns thick to ensure comparable properties to electroplated hard gold films

Cross Sectional TEM

EBSD





- Columnar grain structure is observed with a significant reduction in grain size for Au-ZnO (1 vol%) thin film as observed from this Transmission Electron Microscope (TEM) image.
- Note the difference in scale bars for the Electron Back Scatter Diffraction (EBSD) images.

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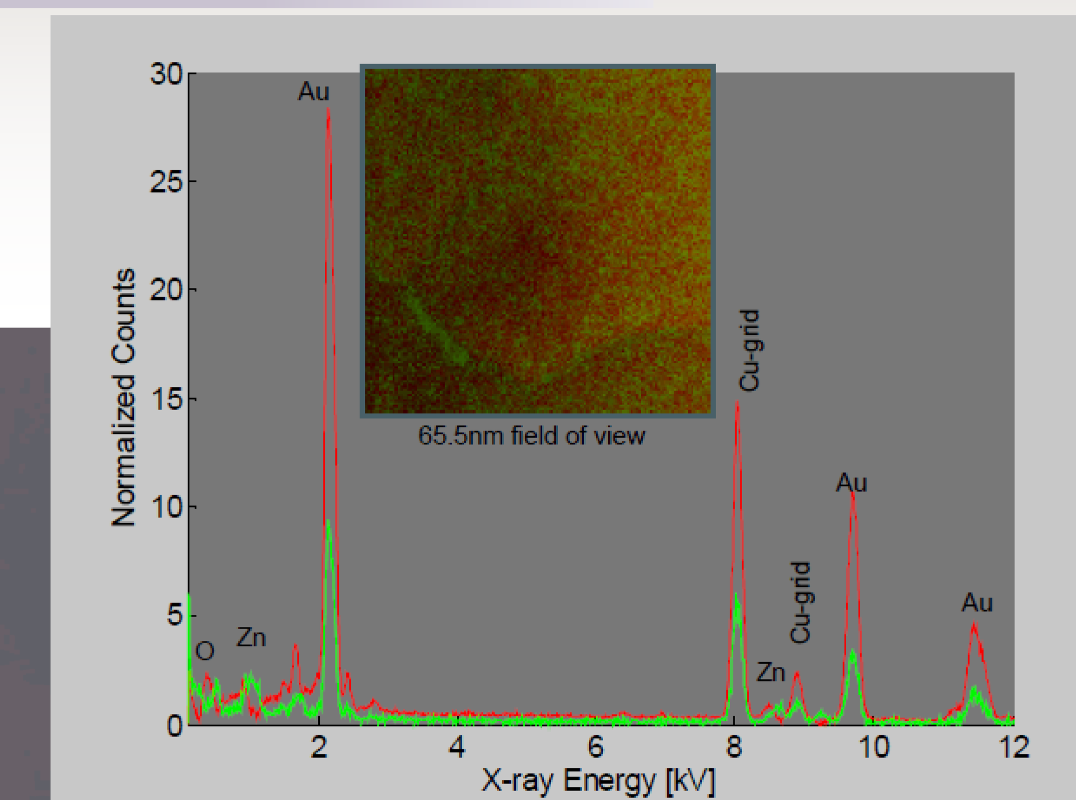
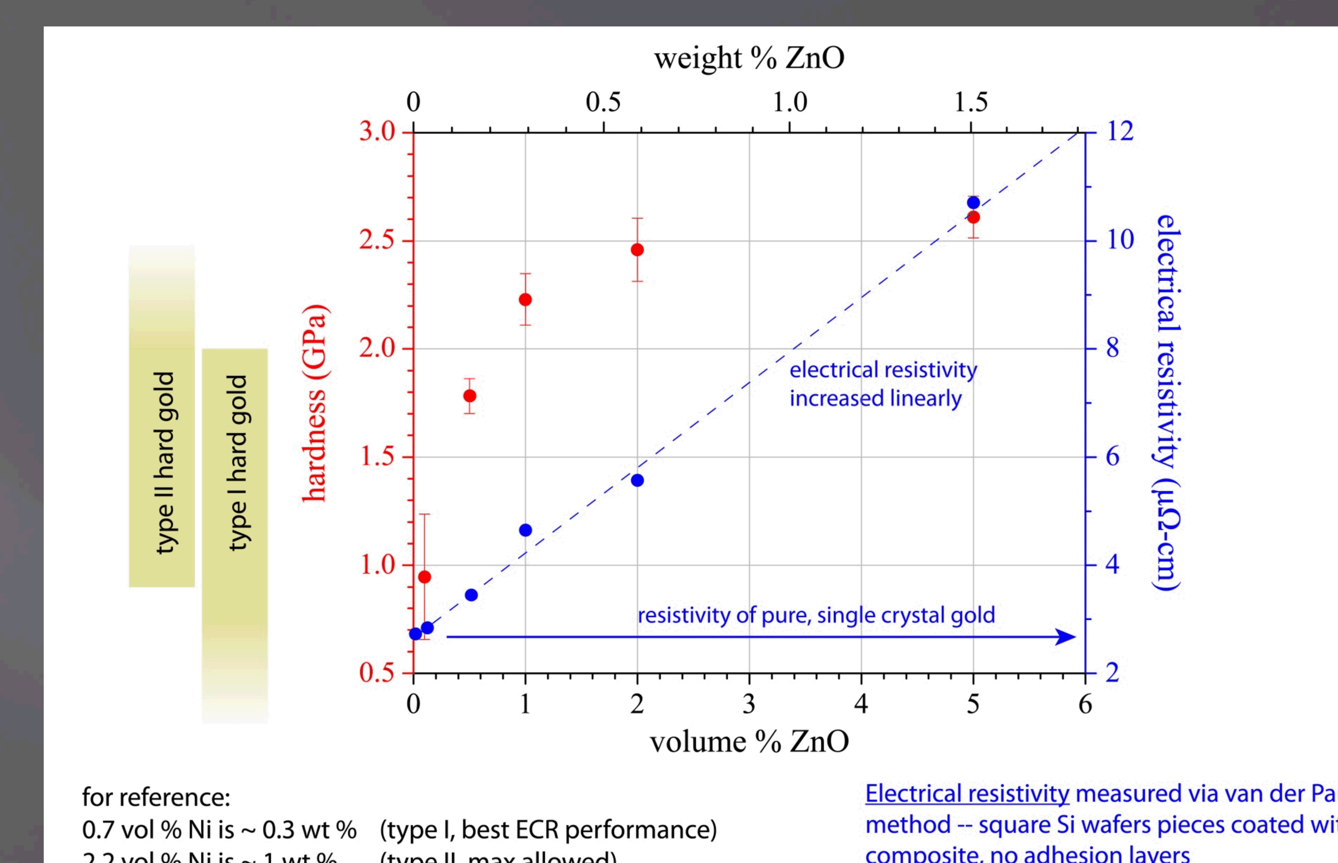
ZnO at Grain Boundaries



The ZnO has predominately deposited at the grain boundaries pinning the gold grain growth. The thin film hardness follows the Hall-Petch relationship where hardness is proportional to the inverse square root of the grain size ($d^{-1/2}$) resulting in more desirable friction and wear compared to pure gold.

Hardness and Electrical Resistivity



Conclusions

We have indeed created a new class of hard gold using e-beam co-evaporation with a ceramic as the hardening agent. Using EBSD and TEM we see the zinc oxide did impede grain growth thus making the gold harder. We also see an increase in resistivity as the ZnO concentrations are increased. Both the increase in hardness and increase in resistivity are due to the reduction in grain size. Au-ZnO is a suitable alternative to the traditional electro-deposition with some advantages. PVD deposition of Au-ZnO is more environmentally friendly. Another advantage over traditional gold is the stability of the ZnO. Since ZnO is an oxide, it should not segregate and diffuse to the surface creating a nonconductive layer.

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