Enhanced Electrical Conductivity of Silver Nanoparticles for High Frequency Electronic Applications

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Coplanar waveguides structures fabricated of metallic silver nanoparticles and sintered at 350°C have a lower sub-THz transmission losses than conductors made of micron sized silver particles sintered at higher temperature of 850°C. The enhancement in conductivity is attributed to the high packing density of particles resulting in a better proximity and lower surface roughness by a factor of three. The research opened up new routes of printing metallic composites on plastic substrates where the low sintering temperatures is required. It is expected that this type of metallic nanomaterials may replace the conventional silver in the production of high frequency circuits which therefore reduce the fabrication cost and time.

1- Fabrication & Measurements

First Stage:
Contact pads Fabrication using Photolithographic Techniques.

Second Stage:
CPW Composites Fabrication using Screen-Printing Techniques.

1-Printing photosensitive paste
2-Drying
3-Exposing
4-Etching / Developing
5-Firing

nAg Ag

Figure 1. Fabrication stages (A)/(B). SEM images show one of the final circuits contact pads structure (C).

2- Structural Analysis

Average RMS roughness ≤ 465 nm

Average RMS roughness ≤ 151 nm

Analysis of the rms roughness obtained from the AFM images (Figure2) indicated that the thick film silver sample has an average rms roughness of 465 nm (standard deviation of 38 nm) compared to that of 151 nm (standard deviation of 25 nm from nine measurements) for the nAg samples. As a consequence the rms roughness of samples made with nanoparticle is approximately 1/3 that of samples made of micron-sized Ag and is attributed to the silver nanoparticles being close packed.

3- Results & Discussion

Loses per unit length were plotted as a function of frequency were found from equation (1).

\[
\text{loss}(dB/mm) = \frac{L_l - L_{ref}}{L_{ref}} \quad \text{Eq.1}
\]

Where:

L: The composites loss in dB
L_{ref}: Gold reference sample loss in dB

Electrical characterization of the CPWs has been performed in the frequency range of 45 MHz to 110 GHz and from 140 GHz to 220 GHz. The average signal-to-noise ratio calculated from measurements made on five different Ag and five different nAg samples is presented in Figure 3. In the lower frequency range, Figure 3(a), the behavior of both conductors is similar with the electrical loss increasing approximately linearly with frequency at a rate of approximately 0.1 dB/mm per GHz up to about 80 GHz, above 80 GHz the losses of the conductor fabricated with nAg are found to be lower and this behavior is continued throughout the whole of the higher frequency range, Figure 3(b), from 140 to 220 GHz.

In Figure 3(c) the loss characteristics shown in Figure 3(b) are plotted in terms of loss per unit wavelength (dB/l). The loss, expressed as dB/l, tends to flatten-off as the frequency increases, which indicated that the loss will become independent of the electrical size of a passive component.

4- Conclusions

1-In excess of 80 GHz the electrical losses from samples fabricated from silver nanoparticles are lower than similar conductors fabricated using thick film silver conductors fired at much higher temperatures.

2-The lower loss at higher frequency are attributed to the lower surface roughness found with the nanoparticles due to better packing of grains and resulted in low conductor losses.

3-This research opens opportunities for low temperature fabrication of flexible antennas and for sub-THz nanoelectronics and interconnects with improved performance. Also, structure benefits of nano-particle materials which can be printed onto flexible substrates to get advantage from their tolerance in bending and curvature applications.

A.H.A. acknowledges funding for a PhD. from the Ministry of Higher Education, Saudi Arabia.


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