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Functional electroless gold Ohmic contacts in light emitting diodes

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Conducting gold pads on light-emitting diodes chips are synthesized by electroless chemical deposition and exhibit no color difference, reliable ability of wire bonding, and high electrical conductivity. A plating electrolyte with a long life time and high stability is developed. The hardness of pads formed by electroless plating is three times softer than those formed by evaporation and the force gauge of the p- and n-pads yields of approximately 55 g. The mechanism of electroless gold plating is elucidated and the functions of chemical reagents are explained using the proposed model. The industrial application of electroless gold plating is feasible. © 2011 American Institute of Physics. [doi:10.1063/1.3624831]

Flip chip technology is adopted in the micro-electromechanical systems (MEMS). A key step in flip chip packaging is the formation of bumps on a chip as interconnections between the chip and the board. Current bumping methods include electroplating and stencil/screen printing of solder bumps on the contact pads of integrated circuit (IC) wafers.¹⁻³ Since gold has a high intrinsic cost, identifying plating method that can provide low-cost deposition is important.⁴

Soft gold produced by electroless plating is used for bonding wire in the conventional method of mounting semiconductor devices on a circuit board.⁵ The stability of non-cyanide baths is less and the gold sulfite complex tends to decompose spontaneously to form a metallic gold.⁶ Adding an amine such as ethylenediamine is well known to stabilize the bath through the formation of a mixed gold complex,⁷,⁸ and adding 2,2’-dipyridine⁹ has been found to inhibit the disproportionation reaction by forming its complex with Au⁺. The addition of As³⁺ improves the brightness of the gold deposit, but it is also known to increase hardness.¹⁰ To enhance illumination from a light emitting diode (LED), the surface through which the light passes is usually roughened, causing problems of automatic identification. Since the various surface morphologies of an electric pad within a chip cannot be identified using the wire bonding system, this work provides a method for synthesizing conducting pads of LEDs with no color difference and high adhesion strength. This work describes the formation of a soft gold pad by electroless chemical deposition on various morphology p-type and n-type GaN substrates and the mechanism of electroless chemical deposition is elucidated to explain how it solves the problem of color difference and enhances the stability of the electrolyte. Electroless chemical deposition of the conducting pads for use in LEDs can reduce processing time and cost.

Gold sodium sulfite, a commonly available monovalent salt, was used as the source of gold, disodium ethylenediaminetetraacetate was the complexing agent, ascorbic acid was the reducing agent, and monopotassium phosphate was the pH buffer. The pH was adjusted to seven by adding KOH and sodium thiosulfate and cupferron were additives. The LED wafers were supplied from Epistar Corporation.

The structure of gold conducting pads that were deposited on GaN substrate by an electroless chemical method were observed and Fig. 1 presents data for gold contacts that were evaporated on a GaN substrate and for gold that was electroless plated on a GaN substrate. Measurements were made in the 2θ region between 35° and 70° and the reflection peaks were obtained at 38.21°, 44.41°, and 64.62°, corresponding to the (111), (200), and (220) facets of gold. The structure of the gold pad was identified as fcc phase and comparing with substrate peaks, the intensity of the normalized gold peaks (111) and (220) following electroless deposition were different from that following evaporation. This result reveals that the gold was prepared by evaporation has preferential orientation (111) and for the gold formed by electroless plating, the grains prefer growing along the (111) and (220). The grain sizes, as determined from the full width at half-maximum of the fcc-Au (111) peaks, exceeded approximately 209 nm and 269 nm for electroless deposition and evaporation, respectively.

FIG. 1. XRD patterns of gold pads formed by electroless deposition and evaporation, and of bulk standard (JCPDS file No. 89-3697).

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The morphologies of gold pads on the GaN substrate were observed. Figure 2 presents the surface morphologies of the p-type GaN and n-type GaN, determined by SEM and OM. Figures 2(a) and 2(c) present the morphology of the gold seed layer, Figs. 2(d)–2(f) present the morphology of the gold pads formed by evaporation, and Figs. 2(g)–2(i) present the morphology of the gold pads formed by electroless deposition. The size of the gold grains of the seed layer on the p-type GaN was around 200 nm less than that of those on the n-type GaN, which had a size of around 1 μm, and the variation in morphology was caused by the surface roughening. As shown in Fig. 2(f), the grains size and brightness of the p-pad were larger and brighter than the n-pad. The reason is that coarser surface with a larger surface area-to-volume ratio promotes the growth of grains and therefore the pad grain size on p-type GaN equal to about 1 μm, two times larger than on n-type GaN. Comparing with seed layers and gold pads formed by evaporation, the large grains and much smoother surface can reduce the scattering of light and appear as the brighter surface. Therefore, the seed layer of n-type GaN is brighter due to the larger grains and after evaporation, the pad on p-type GaN becomes much brighter due to the larger grains forming, and more grains were aggregated to form the thin film. The morphologies of the p- and n-pads formed by electrochemical deposition are similar, and as the deposition rates are increased, the grains connect with each other to form films. As shown in Fig. 2(i), the p-pad and n-pad are equally bright. The morphology directly influences the brightness and the problem of color difference can be solved by surface modulation.

Figure 3 presents the analysis of electroless plating process. Figs. 3(a) and 3(b) show the electrolyte without adding stabilizer, Figs. 3(c) and 3(d) show the electrolyte with adding stabilizer, and Fig. 3(e) shows UV-vis spectra of a solution that is used in the electroless deposition of gold after various plating reaction times. The electrolyte with the chemical agent cupferron, added as a stabilizer, is analyzed to elucidate the mechanism of the function of the stabilizer. Without the stabilizer, the gold particles grow on the wall of beaker and also inside the solutions as shown in Figs. 3(a) and 3(b) without stabilizer, (c) and (d) with stabilizer, and (e) UV-vis spectra of electrolyte with adding stabilizer.
them, aggregating to form larger particles. However, the observation that the height of the absorption peaks does not increase demonstrates that the stabilizer blocks the growth of the gold particles in the solution. Solutions that are used in the electroless chemical deposition of gold are still stable. These observations indicate that the stabilizer can prevent the growth of gold particles and enhance the stability of the gold plating electrolyte.

The hardness of p- and n-pads was measured using a nano indenter system. The hardness of the pads that were prepared by electroless plating was 1.7 GPa and 1.6 GPa, respectively. These pads were softer than those prepared by evaporation (5.0 GPa for p- and n-pad) and so were better for wire bonding. Figure 4 presents that the results of the tests of reliability of wire bonding and the I-V characteristics. Figures 4(a) and 4(b) present the OM images of p- and n-pads following the ball shear test and Fig. 4(c) presents the results of the ball shear test on each of ten chips on a single wafer. The ball lifts of the pads occupy most of the bonding area and the adhesion between the pads and balls is quite good, with no peeling of the pads. The average ball shear strength of the p- and n-pads is 54.8 g and 55.6 g, respectively; the industrial specifications require a strength of over 40 g. Figure 4(d) plots the I-V characteristics, which reveal that the chip can be operated up to the standard driving current and that the working voltage of 3.2 V for the pad that is formed by electroless plating is lower than that of the pad that, 3.35 V, is formed by evaporation. The contacts were also shown to be stable over time with no loss of voltage when operated at fixed currents.

Based on the above investigation, this work proposes a model of highly stable gold pads with no color difference that are formed by electroless chemical deposition (as shown in Figure 5).

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