Additive Manufacturing utilizing Aerosol Jet® Printing Technology for LED wire bond replacement

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Abstract

During the last years additive manufacturing has gained a lot of attention due to material cost saving- and rapid prototyping capabilities. In this paper additive manufacturing was successfully demonstrated using Aerosol Jet® Printing Technology for LED wire bond replacement in order to improve the mechanical stability of state of the art LED modules. LED working samples were fabricated by using polyimide as dielectric and silver as conductive interconnect material.

Shape and thickness of the printed lines were characterized by profilometry. The conductivity of the printed silver connectors as well as the threshold voltage were measured and compared to the commercially used gold wire bonds. Results show a comparable behavior regarding electrical and optical properties.

Introduction

Additive printing technologies caused a paradigm shift in various technological sectors. Research on processes and materials in each new technological sector has to deal with specific challenges. These are discussed in numerous recent case studies [1, 2]. Especially in the field of printed electronics an increasing demand for new innovative, functionalized materials and corresponding process technologies evolved during the last years. According to market research companies like IdTechEx this market will grow dramatically during the next 10 to 15 years.

For some time conductive and insulating structures on various substrates were made by material saving, additive methods like ink jet printing. It is possible to realize short electrical connections to decrease the power dissipation, the variety of materials and the energy consumption during production. Additionally this process is suitable for direct fabrication of connections on nearly any rigid and flexible substrate. First attempts of connecting LED devices close to the chip by electrical interconnects made by ink jet printing are already reported [3, 4]. But the use of ink jet printing is limited due to high currents and low resistivity in the LED technology. Other disadvantages of ink jet printing are: low viscosity of the ink, low solid contents and a limited particle size due to the nozzles geometry as well as low standoff distance to the substrate.

Especially direct-write technologies like Aerosol Jet® Printing have demonstrated advantages compared to other technological approaches when printing high precision electronic circuits on 3D shaped substrates due to a high standoff distance to the surface. Using the Aerosol Jet® Printing Technology it is possible to print high viscose inks containing particles up to a diameter of 1 µm and to deposit more material during one printing path. Based on these technological advantages circuits with a higher ampacity can be realized. A higher ampacity is an essential requirement to run devices with a higher performance.

There are several scientific publications dealing with Aerosol Jet® Printing technology in the fields of organic solar cells [5], production of ring oscillators [6], thin film transistors [7] and the development of novel fuel cells [8]. Until now no approach to the challenges in the area of electrical interconnects with high ampacity and low heat input is shown.

State of the art fabrication of LED modules based on chip-on-board technology comprises some shortcomings in its manufacturing process as well as potential structural sources of failures. One of these weak spots is the electrical contacting of LED chips with surface-mounted contact pads based on bonded wires which are encapsulated in a silicone layer. In the subsequent process steps where LED modules are integrated into luminaires this process is prone to errors. In addition to that the extreme thermal conditions LEDs experience lead to heavy stress between the bonded wires and the surrounding silicone due to different thermal expansion coefficients. As a result, those wires may break and lead to a total failure of a LED module.Within this work dielectric layers as well as electrical contacts of the LED chips are applied by Aerosol Jet® Printing replacing traditional wire bonds to overcome these shortcomings.

Aerosol Jet® Process

The Aerosol Jet® process (Figure 1) uses aerodynamic focusing to deposit functional inks direct from CAD models. The ink is placed into a pneumatic or ultrasonic atomizer which creates a dense aerosol of droplets (1) with diameters ranging between 1-5 microns (2). Subsequently the generated aerosol is carried by a gas (N_2) flow to the deposition head (3). Within the deposition head (4) the aerosol is focused by a second gas flow (sheath gas). The resulting, high velocity converging particle stream is deposited onto the substrate creating fine features with line width down to 10µm. During deposition there is no physical contact between the material being printed and the nozzle. This helps to keep the critical area of the print system clean and free of material build up preventing nozzle clogging and particle stream interruption. The process has a natural standoff distance of 1- 5mm or more from the substrate. Therefore conformal writing on 2D or 3D surfaces can be achieved without changing the z-position of the nozzle within a few millimeter range.

System and Materials

The following printing system and materials were used.
Aerosol Jet Printing System: Aerosol Jet® 300CE Deposition System by Optomec Inc.
Materials: Poly(3,3′,4,4′-benzophenonetetracarboxylic dianhydride-co-4,4′-oxydianiline/1,3-phenylenediamine), amic acid solution electronic grade (Aldrich)
Silver nano ink PG-007 (Paru)

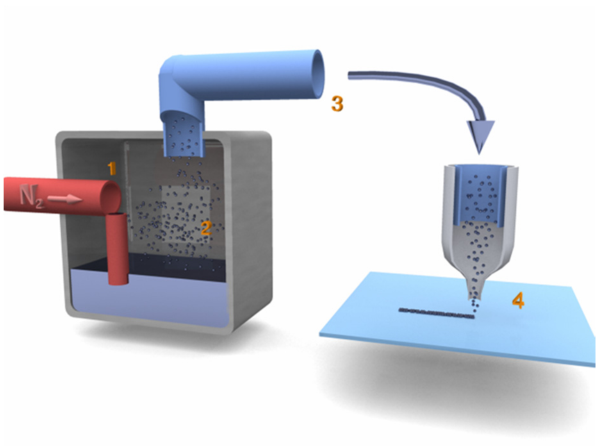

Figure 1. Aerosol Jet® Printing Principle (OPTOMEC, Inc.)

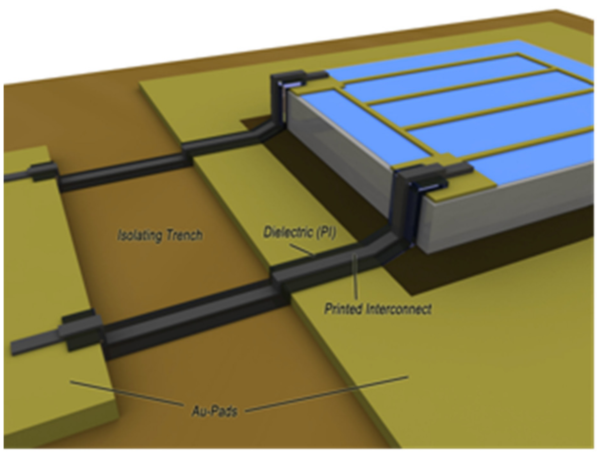

Figure 2: Schematic drawing of printed dielectrics and conductive interconnects of a LED chip using Aerosol Jet® Printing Technology

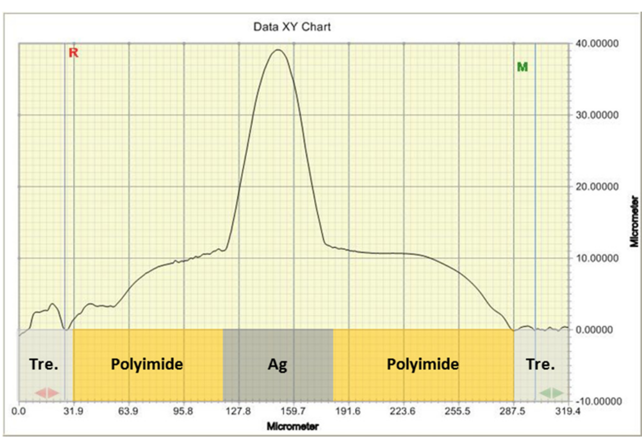

Figure 3: Profilometry image of the printed insulator polyimde and the conductive silver trace on top measured in the isolating trench

Experimental

LED chips with surface-mounted contact pads were used for the present work (Figure 2). Generally printing over chip sidewalls and pads requires either tilting of the substrate or the print head in order to achieve sufficient surface coverage.

In this work the print head was mounted in a 45° angle using a special tilt fixture. All experiments were carried out using the pneumatic atomizer. The aerosol jet printing process with the pneumatic atomizer is influenced by a number of variables. The adjustable process parameters include ink temperature, carrier gas flow rate, exhaust gas flow rate sheath gas flow rate, nozzle diameter, tube heater temperature, working distance, stage speed, and stage temperature.

In the first step a polyimide layer was deposited on the chip serving as an insulator on the one and as a smoothing layer on the other hand. Multiple passes were printed resulting in a 260 µm wide and 10 µm thick and smooth base layer which was cured in a convection oven at 200°C for 30 minutes.

Afterwards a silver layer consisting of multiple passes with a width of 60 µm and a height of about 30 µm was deposited on top of the base layer and subsequently cured at 200°C for 60 minutes to achieve conductive traces (Figures 3-5).

Figure 4: LED chip with dielectrics and electrical contacts by using the Aerosol Jet® Printing Technology

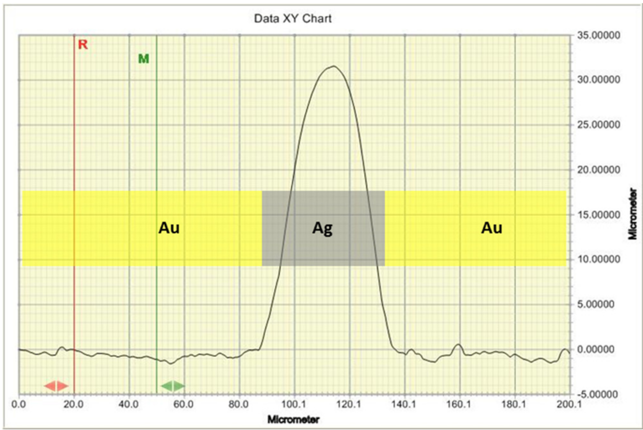

Figure 5: Profilometry image of a silver trace on top of the Au-Pad on the outside of the LED Chip

Results

The aim of these experiments was to electrically contact a commercial LED chip using Aerosol Jet® Printing technology. For the present work an EZ900 Gen II- LED from CREE® was used. This highly efficient InGaN-diode is emitting blue light in the range of 450nm and is die-attached to a printed circuit board. The bottom contact is directly connected via a full faced backside metallization; the top contacts are usually connected by wire bonds (Figure 6).

Therefore two contact pads are applied, each with a size of 150x150µm2, connected with a rough gold grid to ensure a constant light output over the complete device (Figure 7). The chip has a total active area of 880x880µm^2 and a threshold voltage of 2.5V.

All measurements were carried out on an electrical measurement station by MB that is equipped with contact tips for positioning in micrometer precision an optical microscope for fine adjustment.

First of all, the conductivity of the printed silver connectors was measured and compared to the commercially used gold wire bonds.

Looking at the U/I-characteristics (Figure 8), it can be seen that both the wire bonded and the device with printed interconnects show a diode behavior as expected. Exceeding a voltage of 2.6 V, both LEDs start emitting blue light and the corresponding current is increasing fast (just as expected) reaching 100mA at 3V (Figure 9). Below that threshold voltage the diode usually can be considered to be an isolator. While this is the case for the wire bonded device, the LED with printed connectors shows a small current between 1.5 and 2.5V.

The reason for that increase is not quite clear jet, but it is likely to be a nonlinear contact resistance at the cathode side. A leak current due to a defect PI barrier layer would result in a parallel ohmic resistance and would create a linear overlay affecting the complete measurement range.

The LED with Aerosol Jet® printed contacts is very similar in behavior to the commercial wire bonded device. Threshold voltage and luminance at a given voltage of both designs are well comparable.

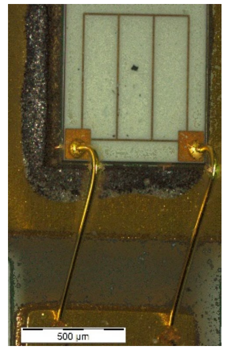

Figure 6: Wire bonded LED chip

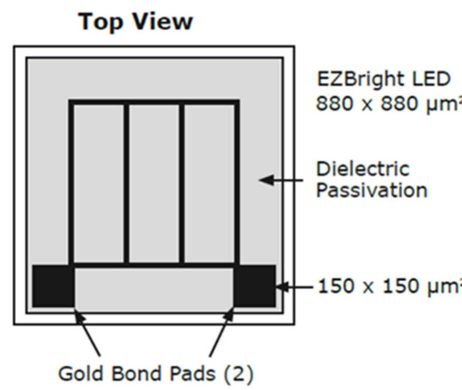

Figure 7: Schematic top view of the LED chip

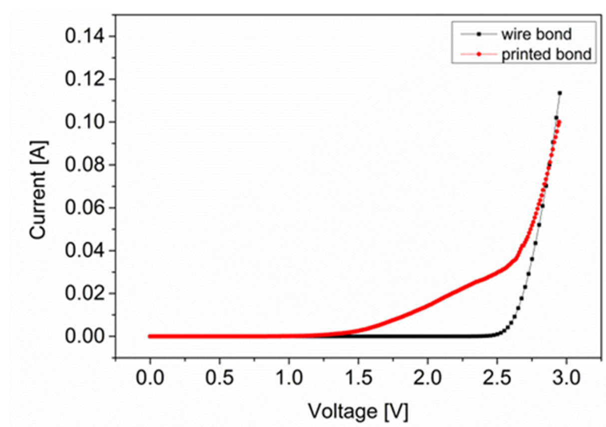

Figure 8: U/I-characteristics of the LED chip with printed dielectrics and interconnects

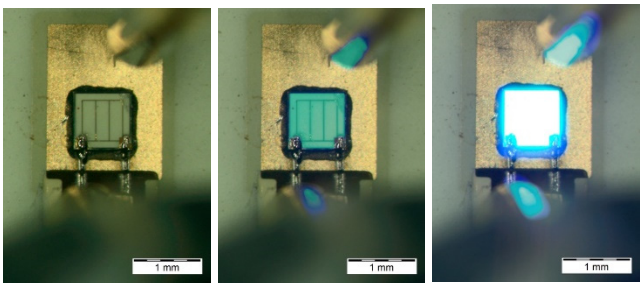

Figure 9: Illuminated LED chip contacted with microprobes.

Profilometry images (Figure 10) show clearly the difference between the unconnected LED (a) and the LED chip after the printing of dielectrics and conductive trace (b).

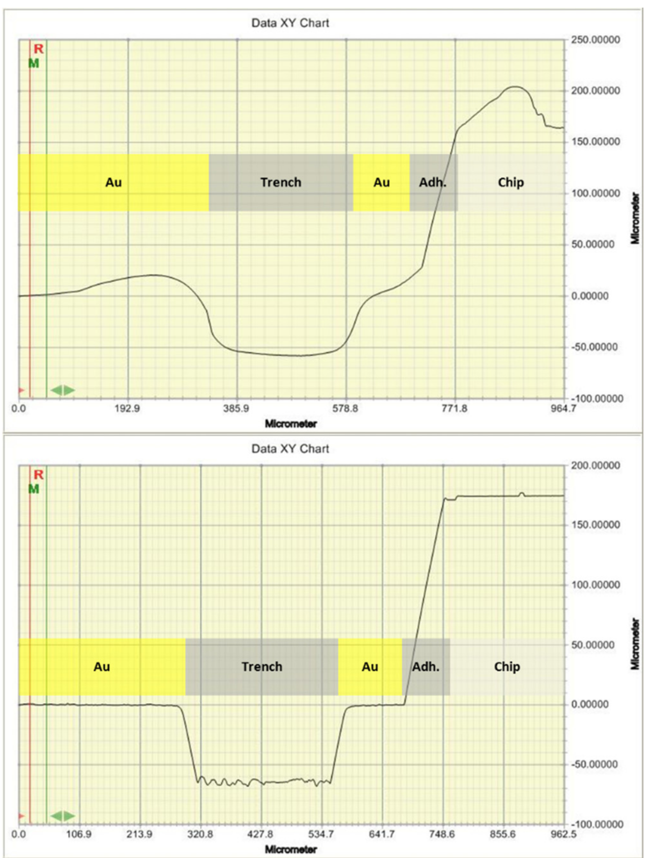

Figure 10: (a) unconnected LED chip (b) Following the top of the silver interconnect with the stylus of a profilometer (Bruker Dektak 150).

Conclusion

Additive Manufacturing was successfully demonstrated using Aerosol Jet® Printing Technology for LED wire bond replacement. LED working samples were fabricated by using polyimide as dielectric and silver as interconnect material. The conductivity of the printed silver connects was measured and compared to the commercially used gold wire bonds and are comparable. The LED with Aerosol Jet® printed contacts is very similar in behavior to the commercial wire bonded device. Threshold voltage and luminance at a given voltage of both fabrication paths are well comparable. Further tests and process optimization has to be carried out in order to improve lifetime and stability of the printed interconnects.

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Author Biography

Andreas Rudorfer achieved the Master degree in Chemistry at the Karl Franzens University in Graz, Austria in 2000. From 2001 to 2003 he joined the company SEZ (semiconductor equipment) and was responsible for process development and application in the area of semiconductor wet chemistry surface treatment. In 2004 he joined Joanneum Research and became senior researcher in 2005. In 2010 he became deputy head of the department "Functional Surfaces" and coordinated NANONET Styria the biggest Austrian nanotechnology network. Main research focus is the development and integration of additive manufacturing technologies like inkjet printing and aerosol jet printing for the fabrication of cheap organic- or inorganic electronic devices comprising less material waste and fewer process steps. Another scope lies on project management for contract- and funded research.