Integration Scheme toward LED System-on-a-Chip (SoC)

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Abstract: Aimed at reducing the form factor of LED systems, we presented an innovative concept of a highly-integrated single platform with successful demonstration by integrating a high-voltage LED, driver and inductor through flip-chip bonding.

OCIS codes: (230.0230) Optical devices; (230.3670) Light-emitting diodes

1. Introduction

GaN-based light emitting diodes (LEDs) have attracted considerable attention from not only the general public, but also from researchers around the world. The cost-effectiveness and minimization of the packaging material for LED devices and systems were the focus of different research groups.

On the cost-effective side, III-nitride hetero-epitaxy growth on silicon wafer was studied and reported for LEDs with different wavelengths [1,2]. The advantages are the lower substrate cost and the availability of large size substrates. In terms of packaging, wafer-level-packaging (WLP) has also attracted a lot of attention. Different packaging methods were studied in order to lower the material consumption in the packaging [3,4].

In this paper, we presented a possible solution of optimizing the cost and the material use by integrating the passive components, LED driver, and LED into a single platform. The first prototype successfully demonstrated the feasibility of the LED SoC technology.

2. Integrated Components

For the design of the high-voltage LED (HVLED) chip, there were 33 LEDs, with the dimension 1 mm ×1 mm, in series so as to construct an HVLED chip. A commercial Epistar GaN-LED wafer was used as a starting substrate and the peak wavelength was 470 nm. The IV-characteristic was analyzed and the connection of the 33 LEDs after fabrication is shown in Figure 1. The design of the HVLED was closely packed, wafer-level connected and flip-chip ready.

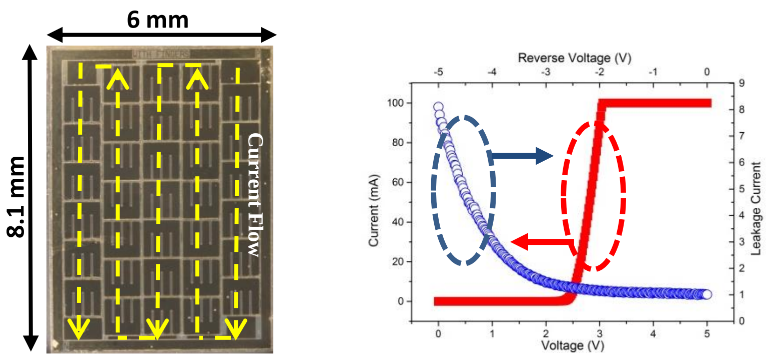

Figure 1 The mask design for HVLED and the IV characteristic of single 1 mm x 1 mm LED

The inductor used for on-chip application was embedded into the silicon wafer, as shown in Figure 2. A small value of inductor resistance was achieved using thick embedded coils, which aimed at increasing the efficiency of the LED converter. The 5 μH inductor was selected for fabricating the prototype of the LED SoC and it had a DC resistance (DCR) of 2.3 Ω with an outer diameter of 5.5 mm, a turn number of 40 and coil thickness of 180 μm. A high-efficiency silicon-embedded inductor with small dimensions for SoC application had the advantage of being highly integrative and having a low DCR.

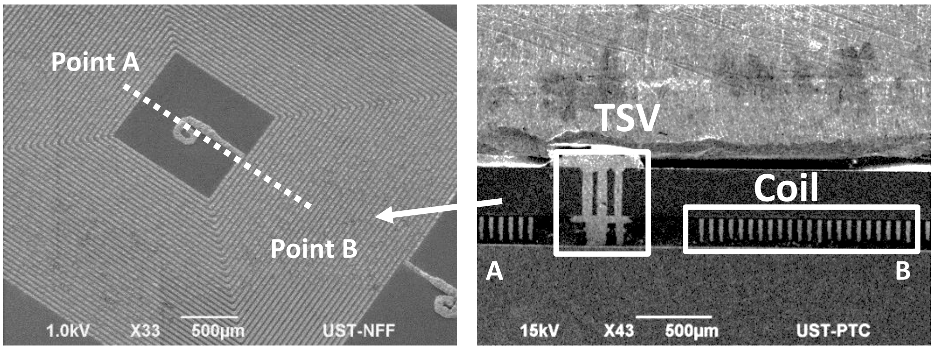

Figure 2 The top view and cross-section SEM picture of the inductor

The whole system was controlled by the single stage integrated LED driver chip shown in Figure 3 [5]. The inverting buck topology was employed because of its simple structure and low requirement for passive components. In addition, the interconnection parasites as well as the system volume were further reduced by integrating the high-voltage power metal-oxide-semiconductor field-effect transistor (MOSEFT) and the controller together on a single chip. The driver was optimized for operating at a 110 V AC input with a 5 µH inductor. We achieved this by increasing the switching frequency and making the converter work at deep discontinuous conduction mode. Finally, it became possible to complete the high level integration of the inductor, power switch and controller.

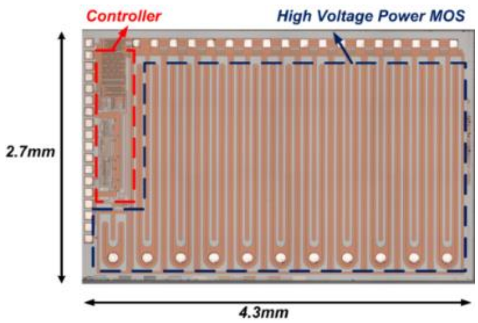

Figure 3 The chip photo of the LED driver

3. Experiment and Results

After all of the components were fabricated, a silicon platform was designed to interconnect them through flip-chip bonding, as shown in Figure 4, by reflowed indium bumps, shown in Figure 5.

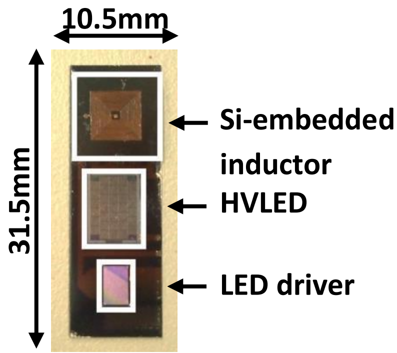

Figure 4 The picture of the LED SoC chip

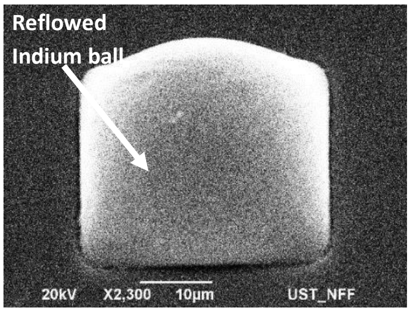

Figure 5 The SEM picture of the reflowed indium bump

The LED SoC was then attached to a Printed Circuit Board (PCB), which provided the off-chip components including rectifiers, power diodes, resistors and capacitors. Figure 6 shows the prototype of the LED SoC, which can be directly powered by a standard 110 V AC line. Figure 7 shows the measured waveforms of rectified input voltage, input current and LED current under 110 V AC at 60 Hz. The power factor measured by a Voltech PM100 Single Phase Power Analyzer is 0.95 and the overall efficiency for the LED driver is approximately 73%.

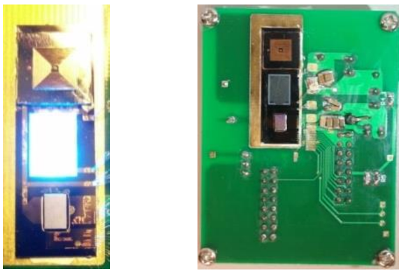

Figure 6 The picture of the final prototype of the LED SoC

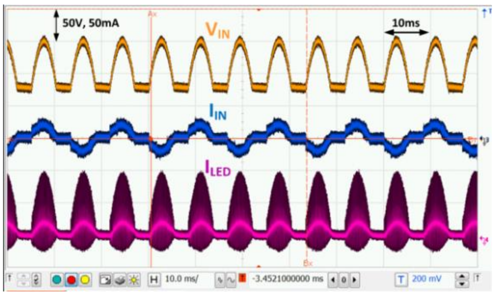

Figure 7 The measured waveforms of LED SoC

4. Conclusion

This study successfully demonstrated the feasibility of monolithically integrating a LED driver and GaN LEDs. The potential of minimalizing LED devices' volume and improving the cost-effectiveness of the general lighting systems can be achieved.

5. References

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