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Silicon-based multi-functional wafer-level-package for LEDs in 7-mask BiCMOS process

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ABSTRACT

Today, finding a low cost, efficient, functional and reliable solution for controlling smart lighting systems has become topic of many research groups and industry. In this study, a multi-functional wafer level package (WLP) for phosphor-based white LED system has been designed and manufactured using 7-mask BiCMOS process. This package integrates 4 high power blue LED dies with a temperature sensor and a blue selective light sensor for monitoring system performance. Each sensor has been designed, characterized and calibrated to be part of the smart monitoring unit. An interdigitated power transistor and a 4-bit flash analog-to-digital converter (ADC) were also monolithically integrated with sensors' readout and extra controlling functions.

1. Introduction

As LED technology is emerging dramatically in recent years, there are increasing demands for improving the luminous efficiency and lowering the cost for manufacturing industry. However, package reliability is still one of the main bottleneck for LED systems [1]. Specially for high power packages, high operating temperature can affect light intensity and color shifting over the time [2].

Among different methods of producing white light for general illumination application, phosphor-based white method is the most common approach. The principle is to produce white light by a single short wavelength LED such as blue or UV, joint with a yellow phosphor coating. This approach acquires higher efficiency, acceptable color rendering, and lifetime comparing to so called trichromatic approaches [3,4].

In addition to general illumination, blue and UV LEDs are progressively applied in medical and sensing applications [5]. Improving the system reliability in general and mainly for more sensitive areas motivates industry to develop more advanced lighting modules. Functional blocks like system monitoring units and innovative color control technology provide the ability to control and adjust the light intensity and color temperature (CT). So, integration of more functions and packaging configurations are some of the critical keys for reliable and efficient solutions for the modern lighting demands. Previously, many integrations were done in PCB level [6,7]. However, silicon-based wafer level packaging can be one of the best promising approach considering cost, efficiency, functionality, design flexibility and uppermost reliability [8,9].

Another concern is large heat dissipation in such a high power package which can also be addressed in silicon based WLP [9–11].

Monolithic integration of photonics and electronics in Si and other group IV elements was previously reported [12–14]. Many groups formerly reported integrations of temperature and optical sensors for the most important parameters of such packages in wafer level [11,15–18]. The authors also published a work on blue selective photodiodes and designed and integrated for LED package [18] and relevant light feedback control circuit [19]. Though, using silicon substrate gives us the opportunity to integrate more

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functional module such as controlling unit and the whole readout circuits.

To address such issues, a new monolithic silicon-based package is introduced which is realized in the 7-mask BiCMOS process. BiCMOS7 process can potentially implement a smart LED driver platform for the cost less than 1–2 $/cm^{-2} [18]. This process flow integrates monolithically the diodes, CMOS and BJT transistors all in just seven masks, which can simplify final package configuration. It is optimized for performance of different passive and active components [18,19]. Final system will be a smart miniaturized LED WLP with two main functions: 1) system performance monitoring and 2) system controlling. The first function involves temperature sensors that monitor the package temperature. This data can be used for thermal management by controlling blocks or for further analysis. The monitoring function also includes blue selective photodiodes specially designed for the target LED wavelength that selectively detect the output blue light intensity. It provides very accurate brightness information of the mounted LED in the package. The brightness information can be later used for a feedback control circuit to correct the intensity and color shifting of the output light [18,19]. The second function, system controlling, determines driving current of LEDs, which can be performed in either analog or digital ways. A 4-bit flash ADC is also implemented for reading out sensor data. It can be used as a part of a digital control system. Next, a high current power switch is integrated for driving the LEDs. In this paper the main blocks are discussed, which are the key elements for a full integrated smart silicon based LED platform.

Having different kinds of sensors in the same package with LED chips and readout circuits in a relatively low cost miniaturized module, can be an appropriate demonstrator for different applications such as biomedical diagnostic devices or other sensitive areas.

This paper is organized as follows: in Section 2, design of the LED WLP is presented with explaining three main blocks: sensors, power transistor, and ADC. In Section 3, fabrication process is summarized with presenting the main steps of the 7-mask BiCMOS method. In Section 4, the implementation and measurement results are discussed. Finally, it will end by a short conclusion of the whole work.

2. Design of LED wafer level package

The package is designed as a high lumen output package integrating 4 BXCD 45 mil x 45 mil Bridgelux® Blue Power Die. The complete die size is 10 × 10 mm^2 including the test and main structures, but the main package is 6 × 10 mm^2. The design is such that 4 LEDs can be turned on in series with any combinations of 1–4. The target LED in this study is a vertical blue power die from Bridgelux®. Some of its specifications can be found in Table 1. These LEDs are useful in a broad range of applications such as general illumination, automotive lighting, and LCD backlighting [20].

The whole design was manufactured using 2 μm 7-mask BiCMOS process. This process, which was developed at Dimes Institute of Microsystems and Nanoelectronics (DIMES), comprises of a 7-mask process that involves both Bipolar and CMOS transistors. Originally the process was developed for training purposes, hence short turnaround time, simplicity and low cost were the main feature. Moreover, its relative low area costs for IC processing, enable 2D integration of IC's with large area devices such as LED chips, in our case 1.1 × 1.1 mm^2. Fig. 1(a) shows the complete die layout which monolithically integrated different components for the multifunctional LED system. Fig. 1(b) demonstrates location of different blocks.

Table 1
Specification of the target LED.

Dimension	1143 × 1143 × 150 μm^3
DC Forward current	Max 700 mA
Reverse voltage	5V
Working temperature	−40 to 100 °C
Optical power (minimum)	340 mW
Dominant wavelength	450–470 nm

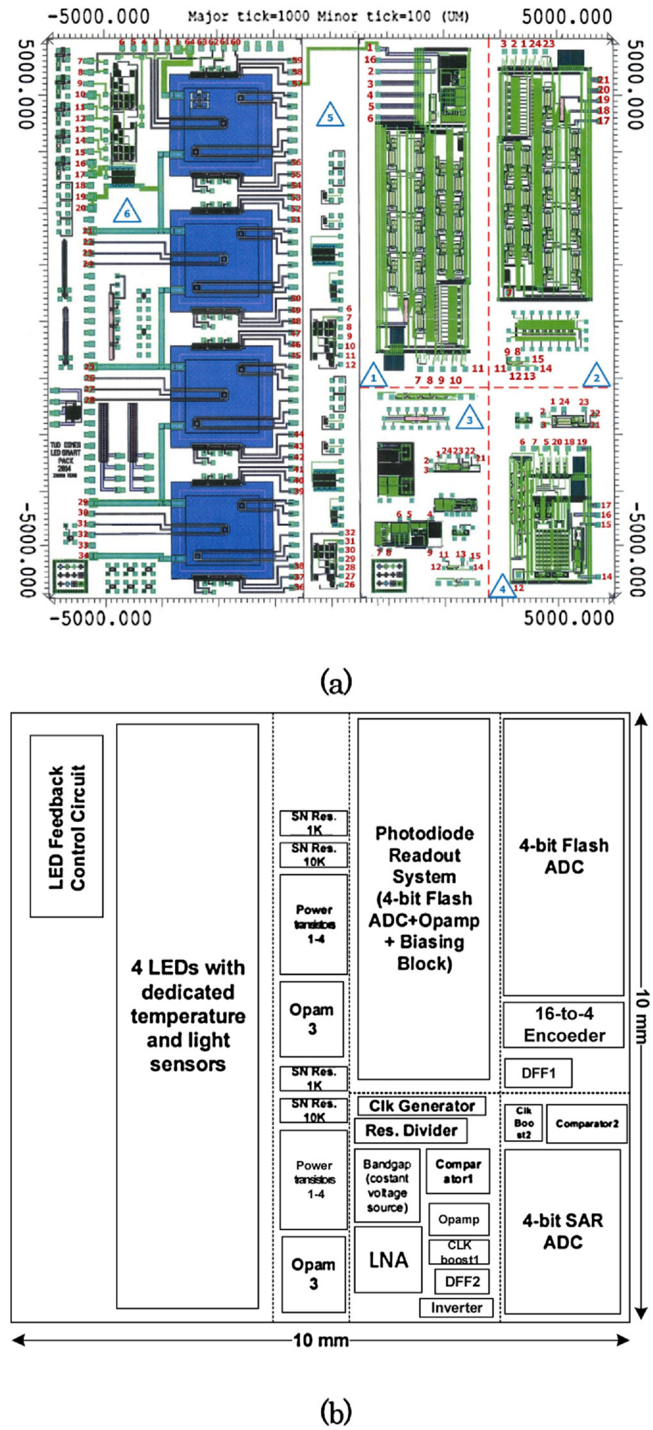

Fig. 1. (a) Layout of the 2D LED WLP and (b) positions of different blocks.

A Temperature and Light Sensors

To monitor the system performance, temperature and light sensing elements were integrated. For temperature sensing, 12 PNP dual junctions are located at different positions under the LED dies.