科学通报 2017 年 第 62 卷 第 12 期：1302 ~ 1306
论 文
《中国科学》杂志社
SCIENCE CHINA PRESS

高温下荧光粉层的位置对 LED 光效衰减的影响

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2016-09-18 收稿, 2016-11-25 修回, 2016-11-29 接受, 2017-03-27 网络版发表
国家自然科学基金(51576078, 51376070)资助

摘要 荧光粉的性能在很大程度上可以影响到LED产品的光效. 关于荧光粉涂覆工艺如何影响LED的光效已经有很多研究, 但是关于荧光粉层的位置对LED热学和光学性能的研究还比较少. 本文采用了一种在线测试的方法, 研究了高温加速实验中荧光粉层位于不同位置时对LED光效衰减的影响. 通过制备荧光粉片, 实现LED模块中荧光粉层的不同位置分布. 对比实验结果表明, 采用荧光粉片的LED模块光效衰减较小, 在散热条件良好的情况下, 荧光粉的发热对其光效影响不大. 对于普通涂覆的大功率LED模块而言, 要提高性能, 其封装内部需要更好的热设计.

关键词 LED, 光效衰减, 加速实验, 荧光粉位置, 在线测试

大功率白光LED由于其卓越的性能在人们日常生活中应用越来越广泛[1~3]. 现有的白光LED技术包括荧光粉转化单芯片技术和多芯片技术(图1). 其中, 采用第一种技术的白光LED最为常见. 这种LED在工作时, 荧光粉受到芯片发出的波长约为460 nm的蓝光激发, 发射出波长约为560 nm的黄光, 这部分的黄光与蓝光混合, 便形成了白光. 荧光粉性能的差异导致其对LED芯片发出蓝光的转化能力不同, 这从源头上直接影响到LED最终出光的品质(色温、空间颜色均匀性、发光强度等). 当LED出光的性能指标中的某些项不满足要求时(例如出光衰减至70%以下), 便可认定该LED失效. 因此, 荧光粉层的性能在很大程度上会影响到LED产品的可靠性.

有研究表明, 荧光粉的转化效率随着温度的升高呈现类似指数形式的下降[4], 并且高温对荧光粉造成的影响是不可逆的, 即使温度降回到常温, 其转化效率也无法恢复原样[5]. 荧光粉的转化效率降低, 使得LED光效降低, 可靠性变差. 因此, 对于荧光粉转化的白光LED模块以及使用该种LED的产品系统而言, 热管理很重要. 一些热管理研究人员的工作集中在LED芯片与封装外表面的热阻上, 通过研究封装材料的性能和热传导路径试图降低热阻, 提高其光效和可靠性[6,7]. 研究荧光粉层在LED模块中的相对位置对其光效和可靠性的影响较少. 在传统的荧光粉涂覆工艺中, 荧光粉胶直接点涂在LED芯片的表面. 当LED工作时, 其热量主要产生于芯片处. 荧光粉胶与芯片接触, 且其导热系数很低(约为0.2 W/m K), 导致热量无法有效散出, 聚积在LED模块内部. 除此之外, 荧光粉对于吸收LED芯片发出的蓝光并非完全转化成黄光, 部分光能量会转化为热量, 从而也会导致荧光粉的温度升高. 这使得荧光粉层的温度可能达到较高的数值, 甚至高于LED芯片的温度[8]. 因此, 有人采用远离涂覆的方法, 使荧光粉层尽量远离LED芯片, 以此来减小芯片产生的热量对

引用格式: 陈奇, 陈全, 罗小兵. 高温下荧光粉层的位置对 LED 光效衰减的影响. 科学通报, 2017, 62: 1302–1306
Chen Q, Chen Q, Luo X B. Effect of phosphor layer's location on LED's luminous depreciation under elevated temperature (in Chinese). Chin Sci Bull, 2017, 62: 1302–1306, doi: 10.1360/N972016-00059

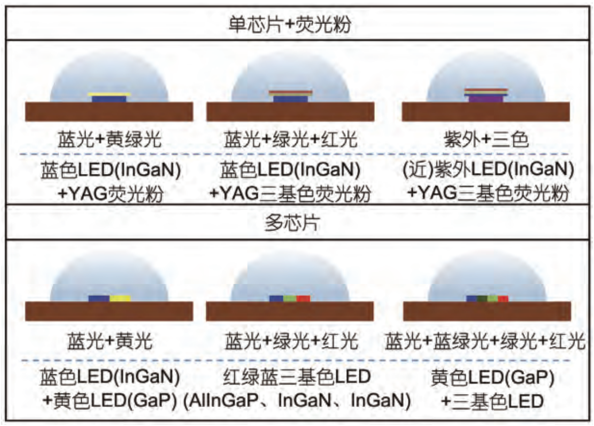

图 1 (网络版彩色)白光LED的发光原理

Figure 1 (Color online) The principle of white light-emitting diode

荧光粉性能的影响[9,10].

在本文中，通过使用荧光粉片，更进一步地改变LED模块中荧光粉层的位置. 利用荧光粉片代替远离涂覆的荧光粉层(图2)，同时采用一种在线测试的方法，研究了高温老化条件下大功率白光LED中荧光粉层的位置对其光效衰减的影响. 实验样品分为3种，分别为未涂覆荧光粉的蓝光LED模块、传统点涂荧光粉胶的LED模块和采用荧光粉片的LED模块. 在相同的条件下经过相同时间的老化，对比分析其光效衰减的模式.

1 在线测试方法

由前人在加速老化实验中的数据可知[11~13]，数据采样间隔时间普遍较长，最短也需几个小时. 在LED模块老化衰减的初期，其光效在短时间内会发生较大变化，如果数据采样间隔时间太长则无法监测到这种变化. 因此，需要缩短LED出光数据采样时间间隔. 最直接的办法是在保证老化过程连续性的前提下，实时地检测LED的出光，但这个方法在高温环境下无法直接实现，主要是因为LED出光检测设备无法耐受严苛的实验环境，比如高温、热冲击和高低温循环等. 对于大功率LED模块而言，高温加速老化实验的主要衡量参数是出光光效的相对衰减. 在我们之前的研究中，提出了一种适用于加速实验下在线采集大功率LED出光衰减数据的方法[14,15]. 其结构示意图见图3.

在图3中，LED模块通过特制的夹具固定在耐高温遮光盒中，遮光盒保证了实验中各组模块的出光没有相互干扰. 遮光盒放置在温度试验箱中(每次5组)，特制耐高温光纤的一端伸进遮光盒，通过特制的夹具固定并与LED模块出光的中心保持共轴，另一端则与多通道数据采集系统相连. 稳流电源驱动LED模块发光，LED模块发出的光通过特制光纤传递至数据采集系统并保存下来. 通过设定多通道数据采集系统的采样时间间隔(最短可达到2 s)，可以保证在短时间内获取大量的实验数据，从而监测LED模块在短时间内的出光光效变化.

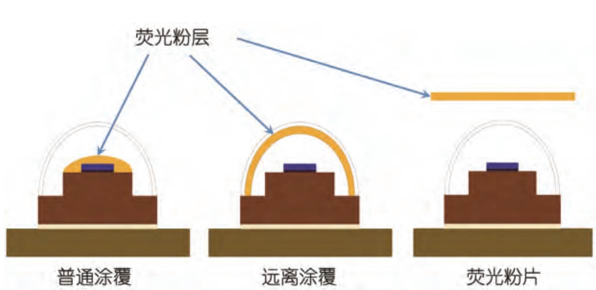

图 2 (网络版彩色)荧光粉层的不同位置

Figure 2 (Color online) The locations of phosphor layers of various packaging patterns

2 实验过程

参照传统点胶涂覆LED样品荧光粉胶中硅胶与荧光粉的混合比例，制备荧光粉胶，将其制成荧光粉片并固化，其结构尺寸如图4所示. 按照图3所示系统连接各实验设备，包括稳流电源、特制夹具、高温箱、特制光纤、多通道照度计、电脑等，加速老化实验温度设为120°C，注入电流设定为350 mA，数据采集间隔设定为30 s，采样总时间设定为48 h. 开展对比实验，将实验样品设定为3组(每组5颗)，第一组样品

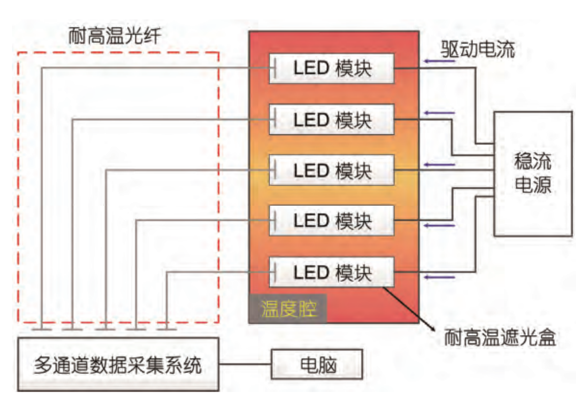

图 3 (网络版彩色)在线测试系统结构图

Figure 3 (Color online) The structural schematic of the proposed online testing system

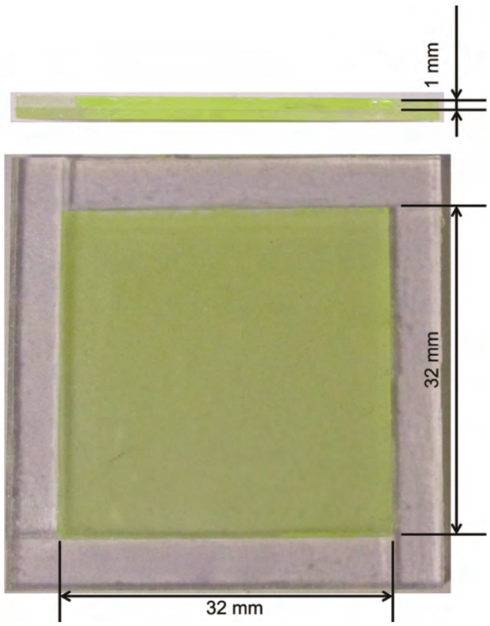

图 4 (网络版彩色)荧光粉片的结构尺寸
Figure 4 (Color online) The phosphor slice and its structural size

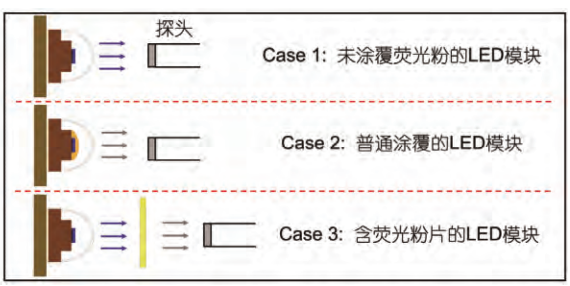

图 5 (网络版彩色)三组实验样品示意图
Figure 5 (Color online) Experimental setups of three kinds of specimens

为1 W蓝光LED模块, 第二组样品为仅点涂了荧光粉胶的1 W白光LED模块, 第三组样品为1 W蓝光LED模块与荧光粉片组合, 如图5所示.

3 实验结果与分析

对于LED模块来说, 光效是其最重要的性能指标之一. 如图6所示, 经过30 h后, 3组样品的出光逐渐稳定下来. 其中, Case 1中蓝光LED模块相对出光在老化初期略有上升, 这是由老化初期Mg掺杂物重新激活[16]以及退火作用[17]造成的. Case 2中普通涂覆的白光LED模块的出光衰减了约30%, 而Case 3中采用荧光粉片的LED模块仅衰减了2.7%, 后者的光效衰减较小. 产生这种现象的原因在于, LED在工作时,

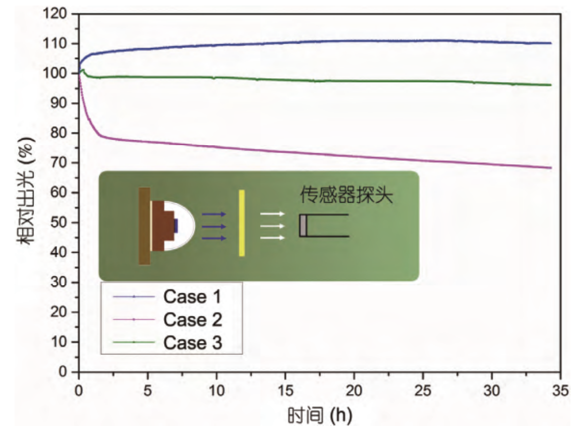

图 6 (网络版彩色)120°C下三组LED样品随时间变化的相对出光
Figure 6 (Color online) Relative light output of three kinds of LED samples as a function of time under 120°C

其芯片的温度较高, 可高于周围环境温度, 而普通涂覆的LED模块荧光粉与LED芯片接触, 且被透镜遮罩, 模块封装内的散热环境较差, 导致荧光粉的温度较高. 除此之外, 荧光粉自身也会产生热量. 当荧光粉颗粒将短波的蓝光转化为长波的黄光时, 一部分的蓝光转化成了热量, 并在荧光粉层内聚集起来, 使荧光粉温度升高, 转化效率下降, 从而引起LED模块出光大幅衰减. 与此相对的是, 采用荧光粉片的LED模块, 由于其远离芯片不与之接触, 芯片产生的热量对其影响很小, 又因为其位于空气对流中, 散热条件良好, 自身由于长波转化损失而产生的热量可以及时被带走, 不产生累积, 荧光粉的温度约等于温度腔内的温度, 因此出光衰减幅度较小. 总体来说, 高温导致了荧光粉的快速衰减, 采用荧光粉片的LED模块光效衰减较小.

4 结论

本文利用在线测试方法, 采用荧光粉片与LED模块相组合的方式, 研究了高温加速实验中荧光粉层的位置对白光LED光效衰减的影响. 通过对比实验发现, 在高温下老化30 h后, 普通涂覆的白光LED模块出光衰减了约30%, 而采用荧光粉片的LED模块出光仅衰减了2.7%. 结果表明, 采用荧光粉片的LED模块光效衰减较小, 在散热条件良好的情况下, 荧光粉发热对其光效的影响不大. 对于普通涂覆的大功率LED模块而言, 要提高性能, 其封装内部需要更好的热设计.

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Summary for "高温下荧光粉层的位置对 LED 光效衰减的影响"

Effect of phosphor layer's location on LED's luminous depreciation under elevated temperature

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High power white light-emitting diode (LED) has been widely used in our daily life due to its extraordinary characteristics of high luminous efficiency, low power consumption, long lifetime and environment protection. Among all the technologies to produce white light, phosphor converting scheme is most popular. In this mode, part of the blue light emitted by LED chip is converted into yellow light by phosphor layer. Then a white output light of blue and yellow light mixture is obtained. The conversion ability of phosphor layer can determine LED's performance parameters including luminous efficiency, correlative color temperature, angular color uniformity, etc. When one of the parameters does not meet the requirement (like relative light output drops below 70%), the LED fails. Therefore, LED's reliability is greatly affected by phosphor layer's property.

Previous study shows that the conversion efficacy of phosphor exhibits exponential degradation as temperature increases. The decrease of phosphor's conversion efficacy can induce light output decrease and deteriorate the reliability. Thus, for phosphor converted LED (pc-LED), thermal management is of great importance. In conventional phosphor coating process, phosphor gel is directly dispensed onto the LED chip. When the LED is working, heat generated by the chip is accumulated due to the poor heat conduction of phosphor layer, resulting in the phosphor temperature rise. Besides, the phosphor's self-heating can also cause phosphor temperature rise. To solve this problem, some researchers used remote phosphor coating to reduce the influence of heat produced by chip. The phosphor layer was moved away from the chip to avoid contact. It means that the phosphor layer's location can have an effect on pc-LED's reliability.

In this paper, the phosphor layer's location was further controlled by phosphor slice. The phosphor slices were prepared by mold to keep specific size. An online testing method was adopted to investigate the effect of phosphor layer's location on LED's lumen maintenance under accelerated temperature life test. Three cases were aged under temperature of 120ºC, namely blue LED module without phosphor layer, white LED module by conventional phosphor coating and white LED module by combining blue LED module and phosphor slice. The lumen maintenance was monitored and recorded every 30 s. After 30 h of aging, the light output of three cases of modules got stabilized. The results showed that the relative light output of conventional packaged white LED module had a 30% drop, while that of the white LED module by using phosphor slice only dropped 2.7%. The reason behind the phenomenon was well explained. Compared with the conventional phosphor layer, phosphor slice was away from the chip so that the heat generated by chip would not affect the phosphor temperature. Apart from this, the phosphor slice was in the air and the good heat dissipation can reduce the influence of phosphor self-heating. Thus, the temperature of phosphor slice was much lower than that of the conventional one and the reliability was somewhat enhanced.

To sum up, the effect of phosphor layer's location on LED's luminous depreciation was studied by online testing system in this paper. Phosphor slices were prepared to achieve various phosphor location and comparison experiments were conducted. The results showed that white LED module with phosphor slice had better reliability. The reason was attributed to the good heat dissipation property of phosphor slice. This work presented an attempt for improving LED's reliability. For conventional packaged LED, better heat dissipation design was needed to improve the performance.

light-emitting diode (LED), luminous depreciation, accelerated life test, phosphor layer's location, online test

doi: 10.1360/N972016-00059