Comment on "Enhancement of flip-chip white light-emitting diodes with a one-dimensional photonic crystal"

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We show that research presented in Opt. Lett. **34**, 301 (2009) applied questionable phosphor definitions and a questionable simulation procedure for light-emitting diodes. Our simulation indicates that a one-dimensional photonic crystal is beneficial for color control but cannot improve the light extraction as asserted in that Letter.

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We found that the conclusions in [1] for the performance improvement of white light-emitting diodes (LEDs) by a one-dimensional photonic crystal (PhC) were based on incorrect phosphor definitions and an incorrect simulation procedure. First, the phosphor thickness was too thin and could not generate a high enough conversion of blue light to contribute to white light. The high scattering factor corresponded to a particle size larger than the incident wavelength and could not make the phosphor thickness physically reasonable. Second, on converting the flux in Table 2 of [1] to optical power by the equivalent eye sensitivity coefficients of blue light (380–490 nm) and yellow light (490–780 nm), the deduced LED spectrums could not yield such a low correlated color temperature (CCT). The CCT of our samples with similar flux output are all larger than 30,000 K. Third, Yt2-1/Bt2 values were 0.1 and 2.4 in LEDs with and without the PhC, whereas Yt1/Bt1 values both were 1.3834. This cannot be theoretically explained. In addition, Bt1/Bt2 values were 9130 and 999 in LEDs with and without the PhC and seemed to be abnormal.

Table 1. Definitions of LED Model

	MQW[a]	GaN		Phosphor	
		P	N	460 nm	560 nm
n	2.54	2.45	2.42	1.47	1.47
$\mu_a(\mathrm{cm}^{-1})$	80	80	80	15	0.5
$\mu_s(\mathrm{cm}^{-1})$				300	280

[a]Multiple quantum well.

Table 2. Results for LEDs with and without PhC

		LED without PhC	LED with PhC
Flux for blue light	Bt1	1	0.9384
	Bt2	0.23306	0.2233
Flux for yellow light	Yt1	11.7259	11.0036
	Yt2-1	2.76795	2.6525
	Yt2-2	16.3972	18.904
Total flux (lm)		32.1241	33.7218
Color coordinate		(0.31, 0.355)	(0.317, 0.37)
CCT (K)		6576	6131

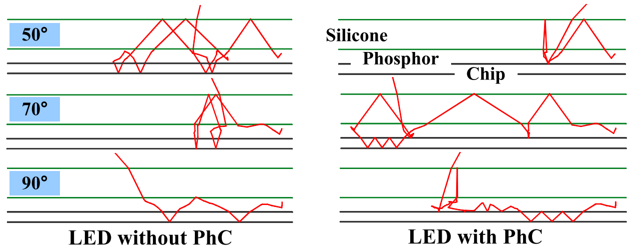

Fig. 1. (Color online) Effects of PhC on light propagation.

To verify the correction of the conclusions in [1], we constructed the LED model and ran a ray tracer. The modified definitions are shown in Table 1. n is refractive index. μ_a and μ_s are the absorption coefficient and the scattering coefficient. The scattering factor of the phosphor is 0.89. The thickness of P-GaN, MQW, N-GaN, sapphire, and phosphor are 0.3, 0.1, 4, 100, and 300 μm, respectively. The back surface of P-GaN is 11% absorption, 83% reflection, and 6% scattering. The simulation results are shown in Table 2. Tested LEDs with similar flux outputs were used to deduce the LED spectrums of simulations to calculate the color coordinate and CCT. Simulation results show that the PhC can lower the CCT but cannot increase the light extraction effectively. The main reason for the differences between our results and [1] is the reflective effect of the PhC on yellow light. Our study revealed that the reflectivity of the PhC at 560 nm is sharply reduced and will be translucent when the incident angle is larger than 30°. As shown in Fig. 1, the strong scattering effect of the phosphor implies that light has a high probability to enter the chip and be multiply reflected between the phosphor and the chip. Therefore, the chip absorption in an LED with the PhC can be comparable with that without the PhC.

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References

1. L. Wang, P.-F. Gu, and S.-Z Jin, Opt. Lett. **34**, 301 (2009).

