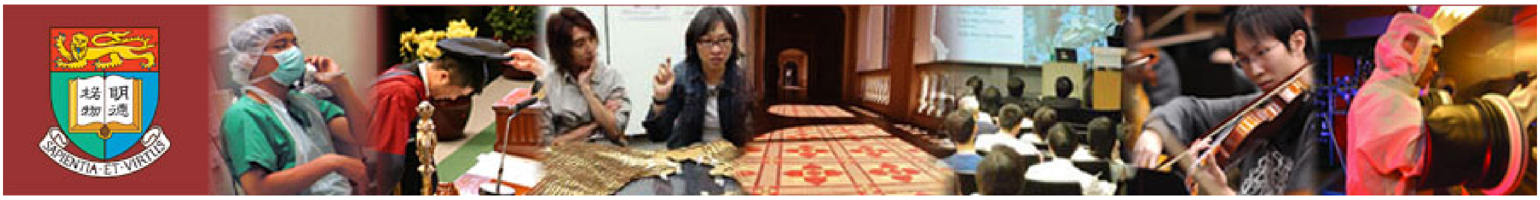

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Designing an external efficient of over 30% for Light Emitting Diode

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I. Introduction

Applications like optical communication systems indicate that as the refractive index of semiconductor materials is quite high (~ 3.5), the critical angle θ_c given by Snell's Law (from semiconductor to air) is very small, typically ~ 17° maximum. Only lights generated in the active region and which strike at the LED surface within the critical angle can escape the device. The small critical angle becomes the limiting factor affecting an LED's efficiency. Therefore, improvements in the external quantum efficiency can substantially increase the LED's overall efficiency. The geometrical design of the LED's surface is also important in enhancing the external quantum efficiency.

LED's having external quantum efficiency as high as 30% [1] can be achieved by fabricating a coarse texturing on the semiconductor surface, where the escape probability of photons can be substantially increased. Nonetheless, the mechanism involved is not yet fully understood. As shown below, the enhanced efficiency is a result of the random nature of the textured surface. It has a greater escape cone than the flat surface; hence, the probability for light to escape is higher.

II. Modeling of the Textured Surface

The textured window layer in the LED can be visualized as having two homogeneous parts. The top part is a rough layer of thickness x, which encloses the highest and lowest point of the surface (Figure 1). The bottom is the bulk of the transparent material of thickness L which extends from the active layer to the lowest point of the textured surface.

The structure is modeled as an upright cylinder, with the top face as the textured surface and the bottom as the active layer. The cylinder is divided into concentric tracks and each track is divided into a large number of sectors. Each sector is modeled as having a slanted and planar top surface with a random inclination. It should be sufficient to consider just a single point source at the bottom surface centre. The total intensity of light emitted is equal to the sum of intensities from an ensemble of point sources evenly distributed on the active surface.

The light rays emitted from the point source are traced. At the point the ray hits the surface in a particular sector, the angle of incidence is calculated and compared with the critical angle to determine if the ray can travel and escape through the surface. The range of angles of the light rays having such capacity is called the escape angle. The total intensity emitted from the entire textured surface is related to the sum of the escape angles for all sectors. The Fresnel reflection loss has been taken into consideration.

III. Simulation, Results and Analysis

The sectored model can be used for the purpose of simulation to estimate the amount of light emitting from the textured surface. During simulation, a random number generator is employed to obtain S_i, the heights of the limiting points of the sectors (Figure 1). The following values for various parameters should be sufficient for the simulation. The width of a track d is 5μm. The total number of tracks, N, is equal to 1001, making a radius of 500μm for the LED. Light rays emitted from the point source at intervals of 0.01° are traced in order to determine the angle of incidence at the surface, which in turn helps to determine the escape angle for each sector. The LED's external quantum efficiency and radiation pattern are studied as a function of (i) the thickness of the textured surface x between 0.1μm to 10μm; (ii) the height between the active layer and the bottom of the textured surface L between 0.01μm to 100μm. The results are shown in the following sections.

A. Thickness of textured surface, x

Figure 2 shows the variations of external quantum efficiency as a function of x and L. As x increases from 0.1μm, the external quantum efficiency gradually increases for all values of L and attains a maximum when x is about 1μm. It starts to drop as x is further increased, and beyond 10μm the efficiency becomes relatively constant.

B. Height between the active layer and the bottom of the textured surface

The external quantum efficiency shows a similar trend as L varies (Figure 2). Let x = 1μm. The efficiency rises as L increases from 0.01μm onwards and attains its maximum at 1μm. It then drops as L is increased further to 100μm. Refer to Figure 2 again for the cases of x=1μm and 0.4μm. As L increases from 0.01μm onwards, the escape probability increases gradually to reach a maximum value. Then, it decreases again.

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C. Radiation Pattern

The high radiance of surface emitting LED can be achieved by confining the emission to a very small area [2]. The radiation pattern of the textured-surfaced LED is more widespread (as shown in Figure 4), unlike that of a typical flat-surfaced LED (Figure 3). It can be seen that the power emitted, or the external quantum efficiency, is much higher in the textured-surface LED than in the flat-surfaced LED. Nevertheless, the power emitted in the normal direction is lower than in other angular positions, and this results in a "butterfly" shape.

IV. Conclusion

In designing high intensity LED's, substantial increase in efficiency can be achieved with the use of a textured surface, which is characterized by its external quantum efficiency and radiation pattern. We have found that the randomness of the inclined façade surfaces contributes substantially to the enhanced efficiency substantially. Such efficiency is strongly dependent upon the textured surface layer's thickness and its distance to the active layer of the diode. To attain the maximum efficiency, an optimal range for these parameters is required.

It is found that the radiation pattern of the textured-surface LED has a wider spread of intensity in the angular direction than the flat surface's. The power emitted in the normal direction is lower, resulting in a 'butterfly' shape. These results serve as guidelines for designing textured-surface LED's.

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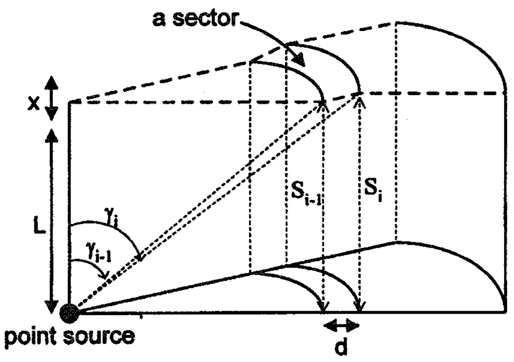

Figure 1 Model of the texture-surface LED using a cylinder

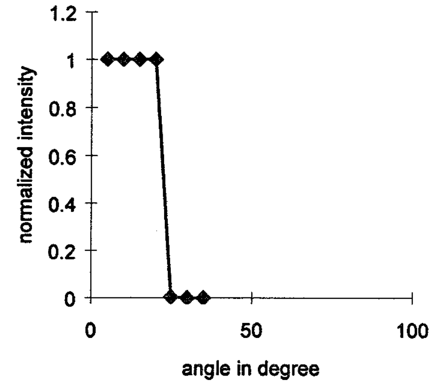

Figure 3. Radiation of a typical flat surfaced LED

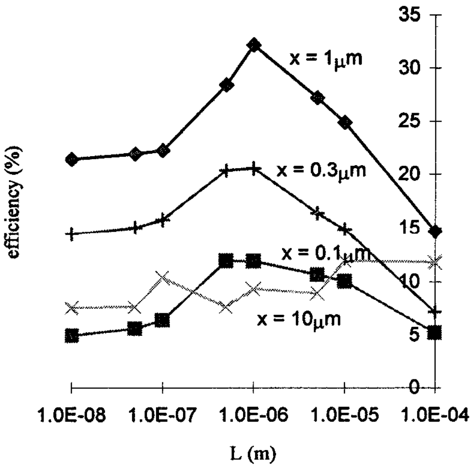

Figure 2. Efficiency as a function of x and L

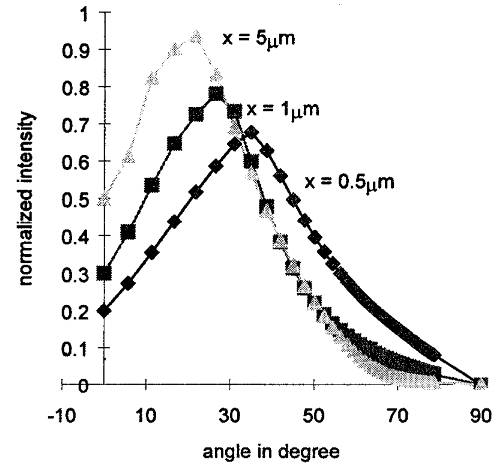

Figure 4. Radiation pattern of a textured surfaced LED