Controlling the Directionality of Spontaneous Emission by Evanescent Wave Coupling

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1. Introduction

Various applications such as projectors, micro-displays for wearable and portable electronics, and biosensors require spontaneous light sources with a well-defined spatial directionality. Despite extensive research devoted to controlling the radiation process of spontaneous emissions, there is still a lack of reliable method for achieving high directionality stable enough for practical applications against variations in device operating conditions. In this paper, we report a novel approach toward controlling the directionality of spontaneous emissions by employing the evanescent wave coupling effect in a small ridge or truncated cone structure.

2. Principle of the novel spontaneous emission control method

The idea is to place a light-emitting region at the center of a truncated-cone structure with a subwavelength-sized top surface (Fig.1). The lateral dimension of this region is smaller than that of the top surface of the truncated cone. When light emitted from the center of the light-emitting region arrives at the two inclined sidewall surfaces at an angle equal to or greater than the critical angle for total internal reflection, evanescent waves will be generated on the two sidewall surfaces. These evanescent waves can be transformed into light propagating in air when they arrive at the top surface [1-3]. Although the propagating direction of the spontaneous emission is random inside the cone, the evanescent waves generated from the spontaneous emission always have a well-defined wave vector directed along the sidewall surface. Therefore, it is reasonable to expect that the spontaneous emission transformed from the evanescent waves has a spatial directionality strongly directed towards the surface normal direction.

3. Experiment and results

To demonstrate the above idea, a light-emitting diode (LED) consisting of an array of GaAs ridges (of width ~520nm) on the light-extraction surface and a stripe-shaped InGaAs/GaAs quantum well (QW) (of stripe with ~100nm) active region embedded at the center of the ridge was fabricated by using micro processing and MOCVD regrowth techniques (Fig. 2). As can be seen from the emission pattern shown in Fig. 3, an emission lobe strongly directed towards the normal direction was observed when measured in a plane perpendicular to the ridge axis. The half-intensity angle was estimated to be as narrow as 43°, which is close to 1/3 that of the Lambertian pattern. We further found that the directionality is almost independent of measurement temperature and injection current of the device. This is a characteristic which cannot be achieved by the conventional microcavity and photonic crystal structures and can be explained by the non-resonant nature of the evanescent wave coupling effect. These features make the present technique very promising for practical applications.

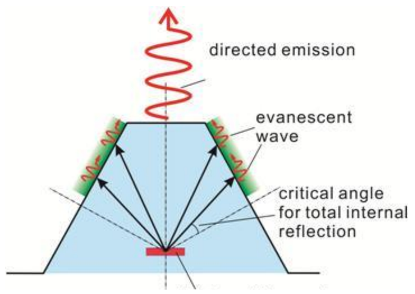

Fig. 1 Cross-sectional view of a truncated cone illustrating the directionality control principle.

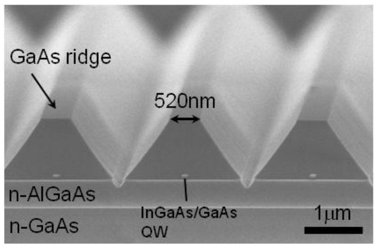

Fig. 2 SEM image of the ridge LED

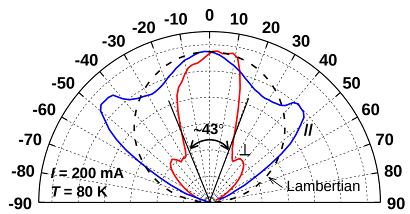

Fig. 3 Emission pattern of the ridge LED measured in plane perpendicular to (red) or parallel with (blue) the ridge axis at 80K under an injection current of 200 mA.

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References

[1] X.-L. Wang *et al.*, Appl. Phys. Lett. **94** (2009) 091102.
[2] X.-L. Wang *et al.*, Jpn. J. Appl. Phys. **51** (2012) 040205.
[3] X.-L. Wang, *et al.*, Opt. Express **22** (2014) 1559.