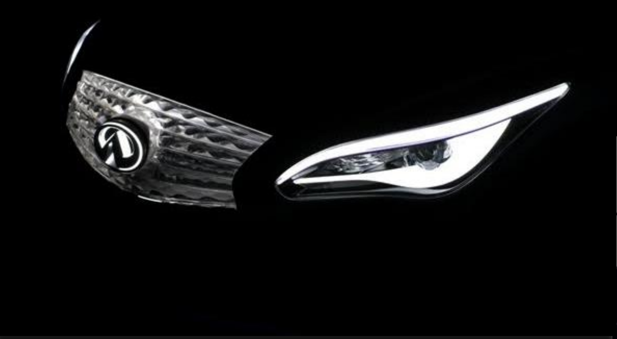
2017

ROLE OF CONVECTION IN HEAT DISSIPATION IN AN AUTOMOBILE LED HEADLAMP



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5/7/2017

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ABSTRACT

LED bulbs are fast replacing halogen and xenon lights in automobiles today. Although LED's offer many advantages like greater service life, efficiency, flexibility in size and color, the heat generated within an LED module is posing a major concern for automobile makers. This build-up of heat calls for the design of LED systems with a cooling mechanism to keep the junction temperature in check. The objective of this paper is to study the performance of LED's designed with a thermal management system. The various parameters which affect the cooling of these systems are identified and their influence on the junction temperature was assessed. A comparison between natural and forced convection was drawn which revealed the significance and contribution of each of them towards the performance of an LED. The possibility of incorporating a water-cooled system was also discussed. Even though the objective of achieving an optimum junction temperature can be achieved with these suggested techniques, limited space is a major roadblock in their effective practical application.

INTRODUCTION

An automobile LED lamp is a device attached to the front of an automobile to provide sufficient illumination during night and when visibility is low. Earlier LED lights were used only as safety light or fog lights but automakers are now replacing the primary headlights and also tail lights (earlier xenon and halogen lights) with LED's. The reason being that LED's offer many added advantages. They have a faster response time, they are brighter, they can emit lights of a wide range of colors. Unlike Xenon and halogen bulbs, LED's do not emit ultraviolet/infrared wavelengths hence making them an environmentally safer option. Another plus of LED’s is that they can be miniaturized thus saving space and adding flexibility to its design.

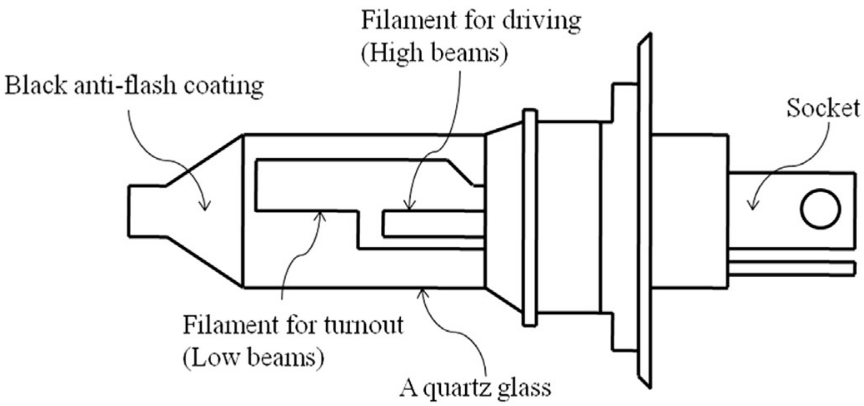


Figure 1: Schematic of Halogen bulb[2]

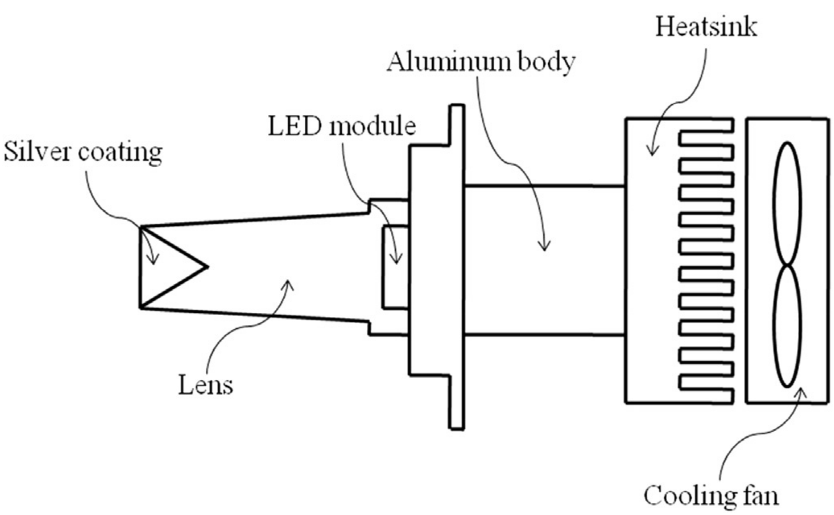


Figure 2 Schematic of an LED lamp [2]

However, regardless of all these advantages, LED lights are known to convert almost all their input electrical power to heat. This heat builds up the junction temperature in the circuit thereby causing its failure. This is a major limitation to the working of LED lamps and it hampers its growth and reputation. There are four crucial parameters which affect the performance of an LED lamp. They are the input power, the surrounding temperature, the resistance between the LED bulb and its environment and type of external cooling.

PROBLEM STATEMENT

LED’s convert about 75%-85% of their input electrical power to heat. This causes a rise in the junction temperature. When the junction temperature exceeds its critical value, the circuit breaks hence causing failure of the LED module.

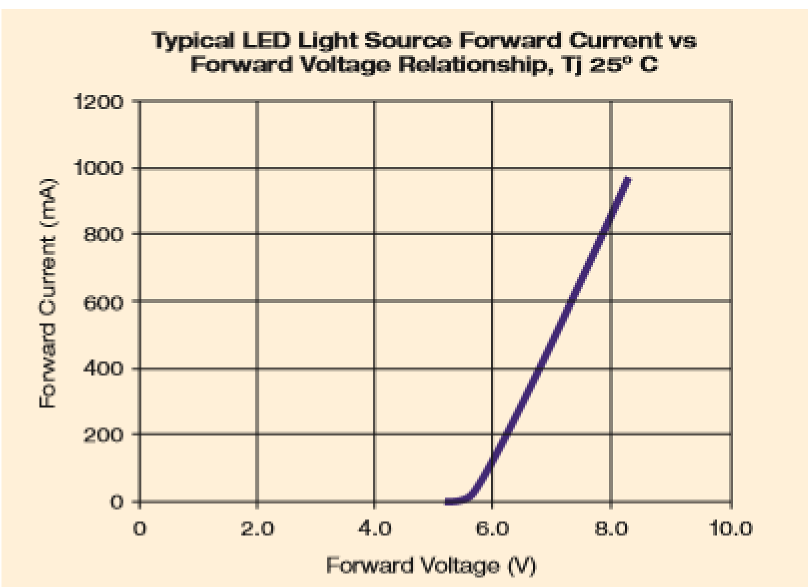


Figure 3: LED light source forward current vs voltage

As we can see in the Fig 2 above, a small increase in the forward voltage results in a spike in the forward current by about 1000mA. This increase in current is accompanied with an increase in junction temperature which fails the circuit. This shows that an efficient thermal management system is needed for proper functioning of an LED. The objective of this system is to keep the temperature of the junction as low as possible. Unlike traditional headlamps, most of the heat generated within an LED is dissipated through conduction and convection. So the thermal system needs to ensure effective heat transfer through these modes.

COOLING METHODS

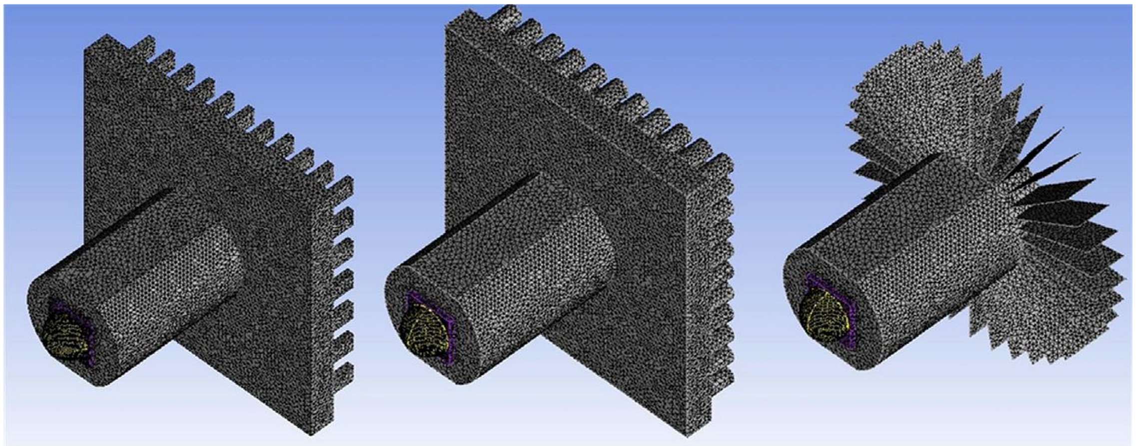
Three different types of heat sinks were designed and analysis was performed using ANSYS fluent to evaluate the conduction, convection and radiation. The heat transfer analysis was analyzed using the Nusselt number which is defined as

$$\mathbf{N_u = h.L/k_a}$$

Where h= convective heat transfer coefficient

k_a= heat conductivity of air

and L= length of the heat sink



(a) Plate-fin type (b) Pin-fin type (c) Radial-fin type

Figure 4:Types of heat sinks

The junction temperature can be calculated by applying the thermal resistance in the following equation:

$$\mathbf{T_j = T_{sp} + R_{j\text{-}sp} * P}$$

where T_j represents the junction temperature, T_{sp} the soldering point temperature, $R_{j\text{-}sp}$ the thermal resistance between the junction and the soldering point, which was stated to be 1.7 ˚C/W, and finally P, the electrical power supplied (24 W). The experiment was performed at 25 ˚C, and measurements were taken using a T-type thermocouple.

NATURAL vs FORCED CONVECTION

Heat sinks with no fins were also analyzed to see if natural convection alone can be enough to manage the junction temperature. This was then compared to the case where a fan was used to force convection.

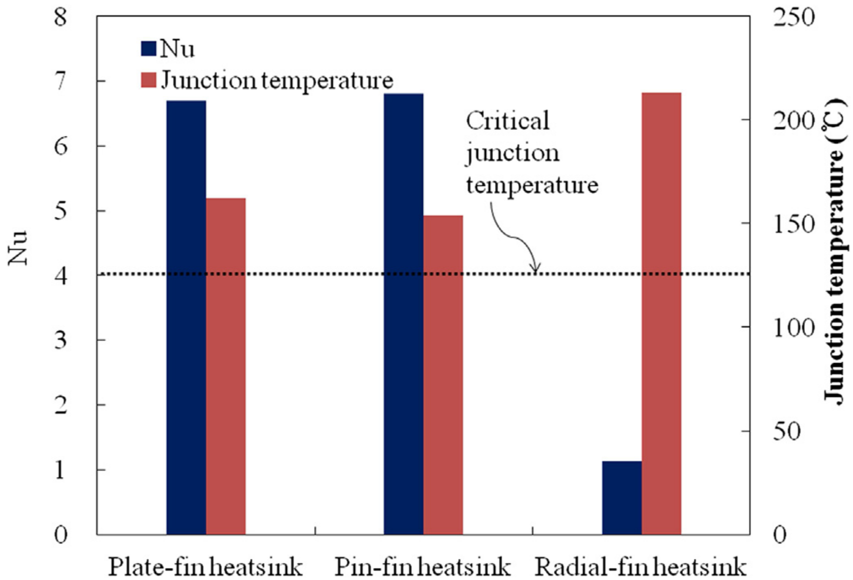


Figure 5: Change in Nusselt number and junction temperature for each heat sink type under natural convection

The heat dissipation performance of plate fin and pin fin is almost identical whereas the Nusselt number is very low in case of radial sink. However as seen in the figure above, the junction temperature under the effect of natural convection rises above the critical temperature (dotted line) in all cases. The Nusselt number is particularly low in case of radial heat sink as there is very little space for the air to move in this case hence leading to reduced convection compared to conduction [2].

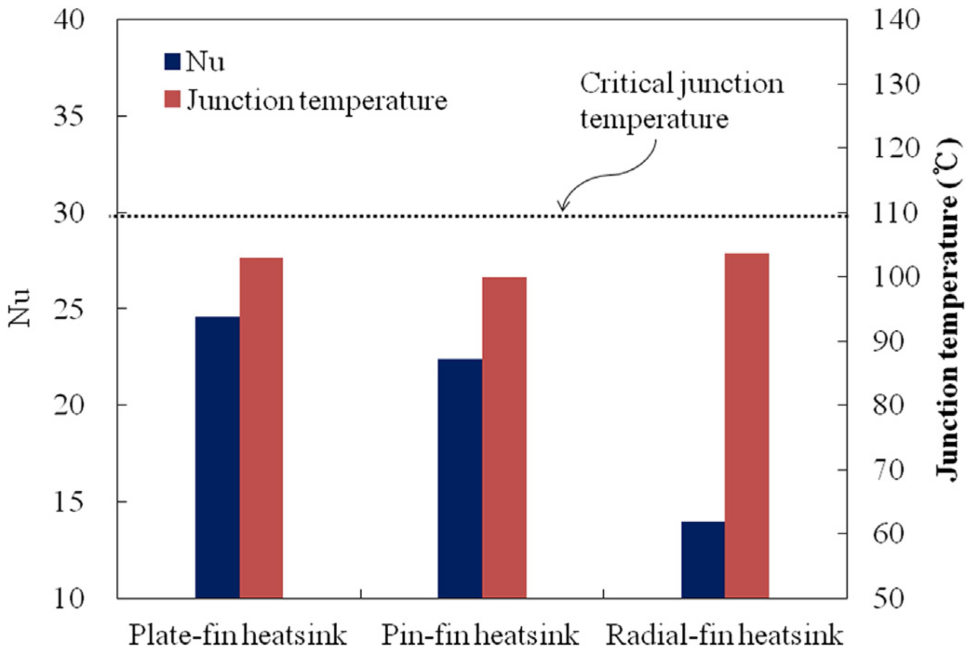


Figure 6: Change in Nusselt number and junction temperature for each heat sink type under forced convection

In case of forced convection, as shown in Fig 5, the junction temperature is well under the critical junction temperature in all the three cases. The convection can be improved by increasing the surface area of the fins. The size of fins is another major obstacle. Amongst the three types of fins, plate fin type and pin fin type are almost equally preferable due to similar performance [2]. The radial fins occupy a greater volume and hence are not advisable.

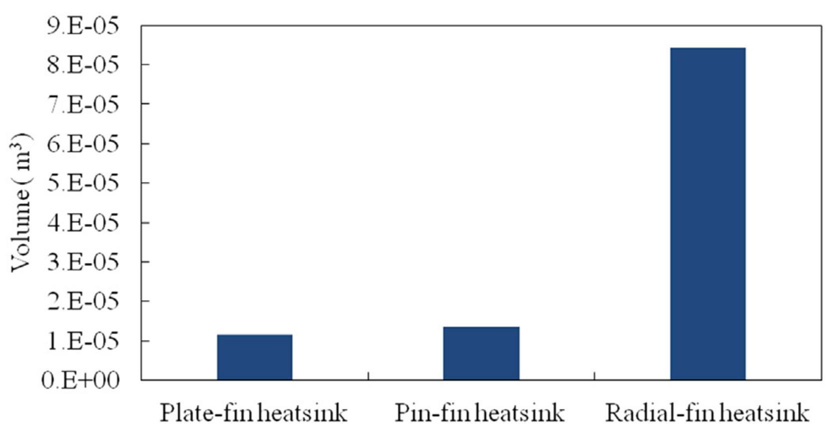


Figure 7: Comparison of volume occupied by different heat sinks

EFFECT OF FIN PARAMETERS

In addition to the shape and type of parameters, a number of fin parameters have to be monitored to optimize the heat sink performance. They are:

1) Surface area
2) Base thickness
3) Fin thickness, fin height and number of fins
4) Material

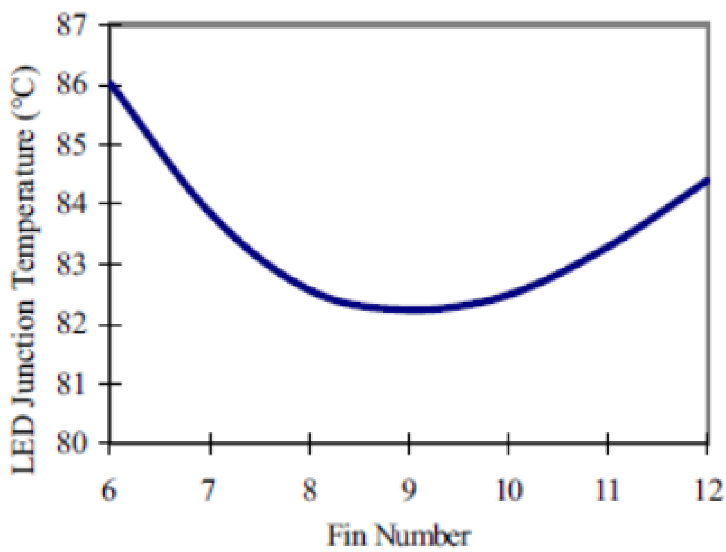


Figure 8: LED junction temperature vs Fin number

The number of fins is dependent on the advancement of manufacturing technologies. Also, the best configuration is selected based on the space availability[4].

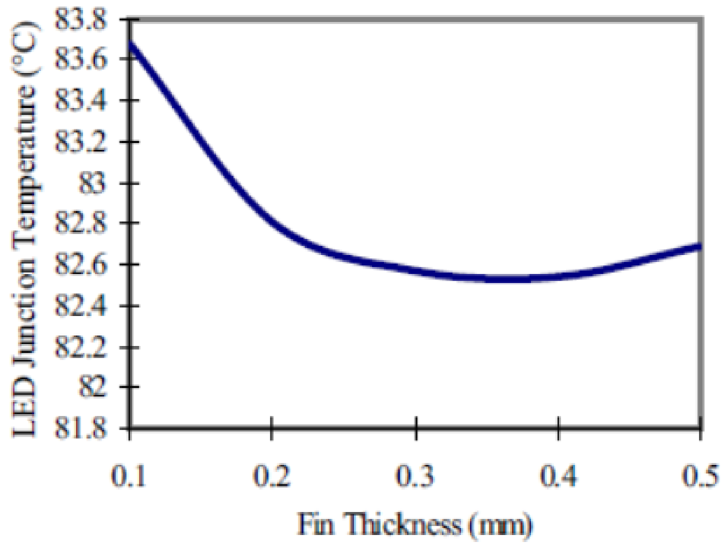


Figure 9: LED junction temperature vs Fin thickness

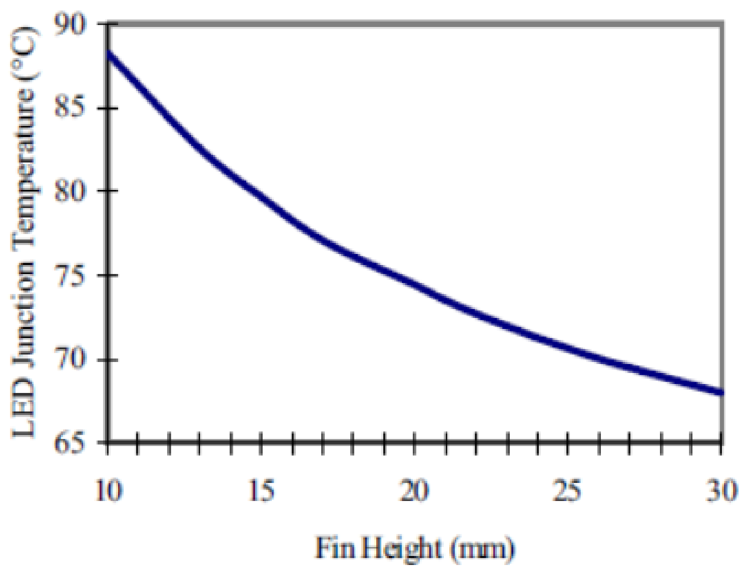


Figure 10: LED junction temperature vs Fin height

The LED junction temperature decreases as the fin height increases which is obvious. But once again, the fin height is limited by the space available. Based on the manufacturing technology available and weight constraints, a maximum permissible fin height is selected [4].

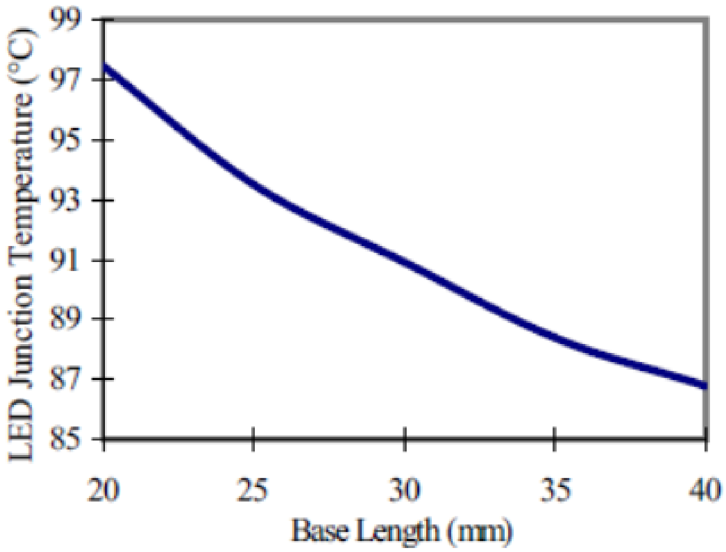


Figure 11:LED junction temperature vs base length

The base height is considered as it spreads the heat across the heat sink. But when the heat sink is placed vertically, the base thickness will not really matter.

LIQUID COOLING

Another case of forced convection proposed was active liquid cooling. Passive liquid cooling was also suggested but the set-up becomes highly complicated and it blocks the light coming from the LED and thus is counterproductive.In this case, the heat exchanger was attached to hoses of liquid. The cold plate attached to the module removes the heat built up and uses the heat exchanger to stay at a low temperature. Among non-metals, water has the highest conductivity and also high heat capacity so it was preferred [4].

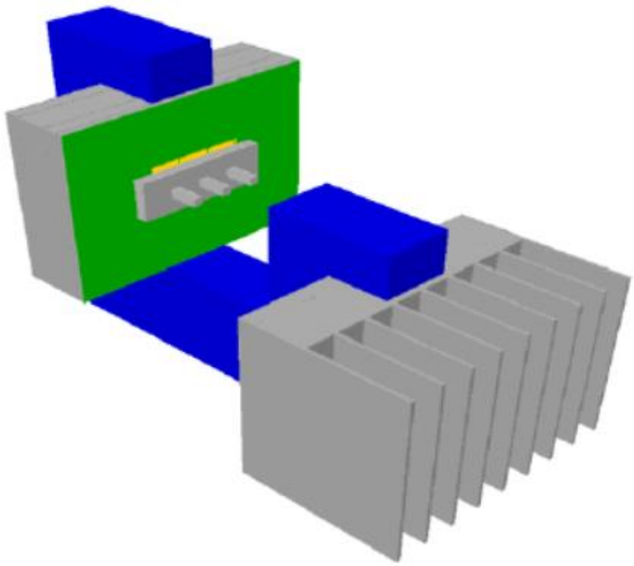


Figure 12:Led module amounted on a liquid cooled plate connected to a heat exchanger

If we plot a temperature profile, a considerable drop in temperature can be seen as compared to active air cooling. But liquid cooling has its own disadvantages such as pumping leakage, extra power consumption and high space requirements.

CONCLUSIONS

This term paper describes the basic functioning of LED's as automobile lamps. It lists the advantages which the LED's offer compared to halogen and xenon lamps. But more importantly the paper describes the most important drawback of using LED's.

LED's pose a major thermal management problem during its operation. Converting almost all its input power to heat, the temperature at the junction rises to an extent where it breaks the circuit. This calls for an efficient thermal management system. The paper discusses how LED's with a heat sink operate under the effect of natural and forced convection.

Natural convection on its own is not enough to keep the junction temperature in check. Forced convection with air cooling was sufficient to maintain an optimum temperature. Forced water with liquid cooling was also studied. Even though this solves the problem of temperature build-up easily, the space requirement is way too high to be accommodated within the automobile headlight casing.

With LED’s becoming more and more favorable by automakers like TESLA, MERCEDES and BMW, they are also being designed to perform with great flexibility. Mercedes AMG GT for example, has LED lights which turn according to the road bend and also adjusts the light according to the incoming traffic. With all these features, additional space is also required. So designers are working on reducing the LED size to keep it to a minimum without affecting its performance.

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