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Novel Thermoelectric Modules for Cooling Powerful LEDs: Experimental Results

V. SEMENYUK[1,3] and R. DEKHTIARUK[2,4]

1.—THERMION Company, 9/11 Tenistaya Str., 65009 Odessa, Ukraine. 2.—Odessa State Academy of Refrigeration, 1/3 Dvoryanskaya Str., 65082 Odessa, Ukraine. 3.—e-mail: semeniouk@thermion.tenet.odessa.ua. 4.—email: d_thermion@te.net.ua.

We present the results of an experimental study of a cooling system based on a novel thermoelectric module specifically designed for thermal management of high-power light-emitting diodes (LEDs). The Seoul Semiconductor LED W724C0 device was chosen for experimental validation of the efficiency of the proposed cooling unit. Two cooling systems with identical heat sinks were tested for comparison: a state-of-the-art one based on an insulated metal substrate-printed circuit board (IMS-PCB), and a system with thermoelectric cooling. The obtained results show that use of thermoelectrics results in a considerable reduction of the LED operating temperature, providing increased light output and greatly increased LED lifetime.

Key words: Light-emitting diode, printed circuit board, thermoelectric cooler

INTRODUCTION

For the same input power, light-emitting diodes (LEDs) are able to provide up to ten times more light than traditional incandescent bulbs. Thanks to their extremely high efficiency, LEDs have become the most useful lighting devices in the last 10 years. In 2003 the US DOE, considering the importance of this trend, initiated the so-called solid-state lighting (SSL) program.[1] Its goal is to cut light energy consumption in the USA by about one-half by 2020 through substitution of traditional light sources by LEDs, which could save the country over US $250 billion in energy costs over that period.

Along with its main function as a light emitter, an LED acts as a concentrated heat source. Only 10% to 25% of the LED power consumption is converted into light, while the remainder is dissipated as heat at the LED *p–n* junction. Meanwhile, LEDs, like all other semiconductor devices, are very sensitive to their operating temperature. Performance characteristics such as lifetime, relative light output, and color stability are strongly dependent on the LED junction temperature. It is seen from Fig. 1 that even a 10°C reduction in junction temperature provides a significant increase in LED lifespan. Therefore, the junction temperature must be kept as low as possible with the dew point as the minimum.

Until recently, the electrical power of typical LEDs did not exceed 1 W to 3 W. The problem of thermal management for such LEDs could be successfully solved by the application of finned heat exchangers subjected to free convection. This situation changed dramatically with the appearance of LEDs and LED arrays with heat dissipation of 10 W or more. Several manufacturers have recently announced the development of such powerful units, destined mainly for use as headlights in automotive applications.[2,3] The thermal management of such devices then becomes a real issue. The main problem lies in the fact that heat rejection is usually hampered due to the severe dimensional constraints which are typically imposed on the cooling system in such applications. Fans are normally not applicable because of the presence of moving parts and additional noise and the strong requirement for long-term operation of the system. As a result, one faces a problem of dimensional mismatch between the small-sized LED and cumbersome heat exchangers adapted for free convection.

Use of thermoelectric technology appears to be a promising approach for LED thermal management

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