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Built-in Low Pressure Drop Liquid Cooling with Internal Graphene Fins on PV/T and CPV modules: Parametric Analysis and Experimental Study

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Abstract

Nowadays, thermal management on PV/T and CPV encapsulation issue still has been a barrier to achieve their impressive performance. Therefore, a novel PV cell cooling module, Liquid-Cooling with Graphene Fin, was introduced in this research to solve the problem. The module, which can be able to built-in to PV cell, was studied on graphene's impact to combined direct and indirect contact cooling performance. Entry region enhancement was also considered and optimized cooling water flow rate to gain both of high heat removal and low pressure needs. The experimental test result also validated the interesting cooling ability of 4.7cm^{2}K/W between back substrate surface and cooling water while still having pressure drop below 0.5mbar.

1. Introduction

Photovoltaic/Thermal (PV/T) module, which uses water liquid to cool PV cell before being consumable warm water, has been introduced for decades ago. However, PV/T still has not yet achieved low cell temperature due to two main problems [1]. Also, Concentrated PV (CPV) module has the same issues that are high thermal contact resistance (R_c) from back sheet substrate (PVF or Tedlar), to cooling channel surface, and high thermal resistance of cooling module [2].

Typical mounting technologies, as compression method with thermal interface materials and adhesive/thermal bonding method, cannot perform very well because of PV module's material properties of brittle silicon wafer and anti-sticky Tedlar, respectively [1-3].

Advanced cooling techniques, as mini/micro-channel and impingement jet, can cause huge amount of total pressure drop (ΔP) through all thousand PV modules on average 20m^2 panels for a residential building. Each PV/T module should have pressure drop less than 0.5mbar (50Pa) to can be used with nominal household 1bar water pump.

Therefore, a Direct-contact Liquid Cooling in macro-channel size (DLC), which has zero thermal contact resistance and low pressure drop, seems to be the solution. However, only macro-channel of DLC still has unimpressive thermal performance. So, Graphene with very high thermal conductivity was introduced to increase the performance as being internal fin. This research has aim to study cooling ability of the Liquid Cooling system with Graphene Fins (LC-GF) for PV/T and CPV modules as built-in unit.

2. Methodology

Theoretical calculations were performed to compare the thermal resistance from Tedlar surface to water ($R_{th,s-w}$) of LC-GF, 3mm channel DLC and Indirect-contact liquid cooling (IDLC). Then, dimension of LC-GF was chosen to optimize flow rate from pressure drop and developing flow's heat transfer enhancement. Later, 3D printing modules of LC-GF and DLC were built and measured their performance in experiment. Panasonic PGS was used for studying as multi-layer graphene. Finally, PV/T and CPV abilities were implied in conclusion.

3. Results and Discussion

Parametric Analysis: fin diameter

In fully developed flow and macro-channel condition, $R_{th,s-w}$ of DLC was better than IDLC, due to have zero R_c, as shown in Fig. 1. Next, Liquid Cooling module with Aluminum Fin (LC-AlF) showed better $R_{th,s-w}$ than DLC when circular fin diameter less than 6.5mm, while LC-GF was better for all diameters. So, thermal ability of graphene can enhances the performance on combined direct and indirect contact cooling concept. However, the suitable fin diameter has to larger than 4mm as PGS sheet cannot be roll with less 2mm radius without destroy graphene layer.

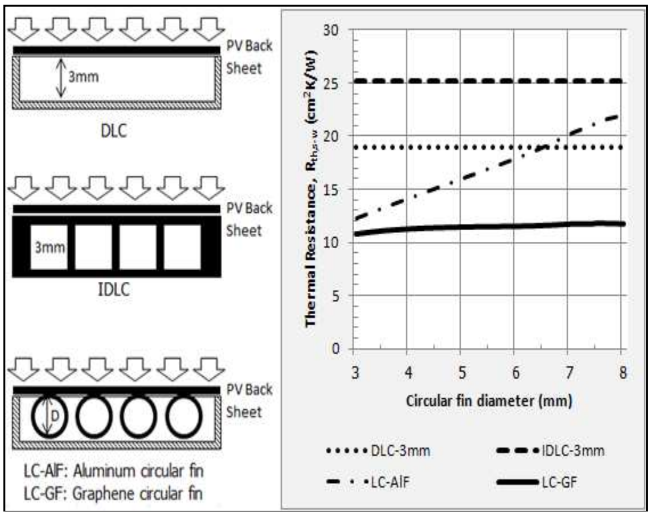

Fig. 1 Comparison of $R_{th,s-w}$ in all four cooling systems.

Parametric Analysis: Flow Rate and Pressure Drop

In order to calculate pressure drop through both modules, DLC and LC-GF, simultaneous developing flow effect on ΔP have to be considered. Fig. 2 shows the optimized water flow rate 1.2LPM for DLC and 0.4LPM for LC-GF to have acceptable ΔP. Furthermore, the calculation showed that, at 0.4LPM, the first quarter length of LC-GF is under combined entry zone and all left three quarters distance is in thermal entry zone. So, heat transfer will be enhanced from low Nusselt number (Nu) on fully developed flow to higher Nu on two types of developing flow and predicted the performance.

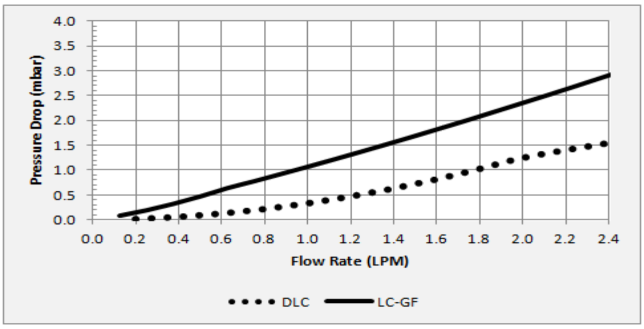

Fig. 2 Pressure drop and Water flow rate.

Experimental study

Module DLC and LC-GF were built by 3D printing to embed two small inlet and outlet manifolds for maintaining uniform velocity and pressure across section area, as shown in Fig. 3 (1-2). Adhesive bonding was applied between graphene roll fins and back substrate, as demonstrated in Fig. 3 (3).

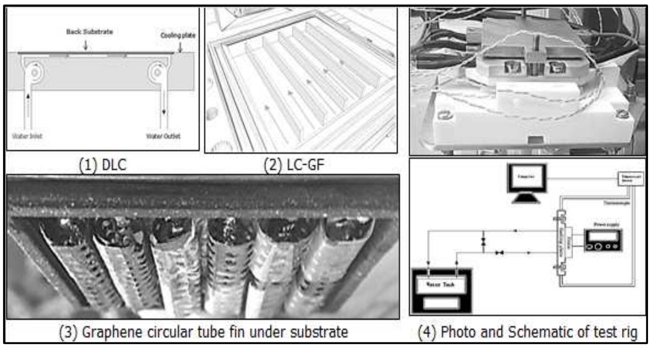

Fig. 3 Schematic of DLC and LC-GF modules for cooling performance test.

The result of both DLC and LC-GF when delivering thermal energy as 32sun solar radiation was shown in Fig. 4. As expected, LC-GF presents nearly twice better than DLC on performance of lower temperature difference between back substrate and inlet water cooling. Combined direct /indirect contact cooling and graphene proved their worthy of usage. Besides, theoretical $R_{th,s\text{-}w}$ based on fully developed condition was reduced almost 50% from 11 to average $4.7 cm^2K/W$. This mentioned the strong effect of simultaneous developing flow at entrance region, which can also be seen on increasing slopes of temperature plot in Fig. 4 at the early position of both modules.

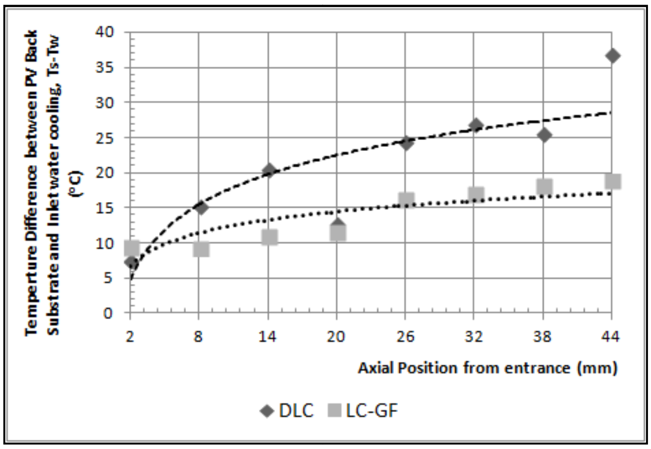

Fig. 4 Temperature Difference between Tedlar and Inlet water cooling when using DLC and LC-GF modules on heat flux $32 kW/m^2$ (32sun) with 0.4LPM water flow rate.

Finally, PV cell temperature can be implied from Tedlar temperature with $24.5 cm^2K/W$ thermal resistance of EVA and Tedlar layers [3]. Therefore, thin LC-GF module with total $29.2\ cm^2K/W$ thermal resistance from PV cell to water cooling can be built-in to PV/T to reduce power efficiency loss by controlling PV cell at 25-35^oC and to CPV for being feasible use in 20-100sun with impressive efficiency [2].

4. Conclusions

Liquid-Cooling with Graphene Fin, showed both great thermal and fluid flow performance through calculation and experiment result for PV/T and CPV modules. The low thermal resistance was mainly achieved from three main heat transfer improvements. Direct contact liquid cooling allowed the cooling water to remove heat without involving to PV cell encapsulation problem of silicon wafer and back substrate properties. Also, providing low pressure drop along the module. Graphere fin increased internally convective surface and change opening shape and area with low thermal conduction resistance. Matching flow rate with module length extended both hydrodynamic and thermal developing lengths to enhance heat transfer coefficient.

References

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