Laser Surface Engineering of Copper Plates: A Laser Texturing Approach for Enhanced Electronics Cooling

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Abstract. The demand for energy is increasing with the advancements in high performance computing systems. The waste heat generation in computing systems can be overcome by efficient cooling systems. Over the last two decades, Laser surface texturing has shown remarkable performance at automotive contacts, mechanical seals and bearings. LST has been used for reducing friction and wear, enhancing lubricant retention, enhancing wettability and heat transfer. In this current study, LST was used to texture copper plates for electronic thermal performance improvement. Three groove patterns were selected and compared with un-textured sample. Thermal characteristics were evaluated using hot plate testing, and wettability performance was measured using laser confocal scanning microscopy, optical microscopy, and contact angle measurements. Results indicate that for electronic cooling application, laser surface modified copper samples can provide better heat dissipation. LST samples showed 2 °C reduction in temperature. The reduction can be attributed to improved wettability. The enhanced wettability may cause better thermal paste integration and efficient heat transfer.

1 Introduction

With the advent of the modern era of artificial intelligence and related digital technologies, unprecedented resources are now being spent on expanding digital data centers that draw more computational power. These energy-intensive data centers demand more electricity, thereby contributing to higher energy costs and more carbon emissions [1]. To cater to and offset such demand, it would be crucial to provide efficient heat transfer mechanisms that not only enhance the thermal management performance of miniaturized electronic devices but also prevent overheating and thermal throttling while maintaining system stability [2].

Processors produce heat based on the principle of Joule's law of heating, wherein the rate of heat production in a conductor depends on the current and resistance. As the number

of transistors in a CPU increases, it involves more inherent resistance [3]. Electrical resistance, in addition to the transistors switching processes, current leakage, higher power density, and inefficiency of electronics, could lead to continuous heat generation. It is essential to prevent overheating, as it can lead to system failure and reduce the lifespan of the central processing units (CPUs) [4]. It is now becoming increasingly important to keep these computer chips cool, and effective cooling solutions are required. Various cooling techniques, either standalone or in hybrid form, are employed, such as thermoelectric cooling [5], liquid cooling, heat pipes, and microchannel cooling, to address this challenge [6].

One of the techniques to create engineered surfaces for enhancing heat transfer is laser surface texturing (LST) to create micro features with novel geometries [7]. Laser-inspired manufacturing processes utilize high-energy photon-based energy beams to machine, drill, mill, and polish various metallic and non-metallic substrates. Laser-based processes offer a non-contact method wherein the interaction of the tool with the workpiece could be avoided, which would otherwise induce plastic deformation and residual stresses in the material of interest. A laser produces a highly intense and focused beam that could propagate and travel at a much faster speed, thus providing faster and more efficient material removal rates that could target localized regions.

With LST, various texture patterns and shapes can be created in the form of grooves, ridges, and other features. One advantage of laser surface texturing is that it can enhance heat transfer and is flexible, accurate, and controllable in addition to being environmentally friendly [8]. The surface features created by LST increase the surface area, which can lead to improved heat transfer performance [9]. In this research, various texture patterns will be created on a metallic copper cooling plate using the LST process. LST process is used to create different groove patterns, which alter surface wettability, contact angle, and spreading area of the cooling plate, thereby enhancing heat transfer in the CPU cooling system. The LST samples will be used to simulate the electronics cooling system, and the temperature profile of textured and un-textured cooling plates will be compared.

2 Methodology

For laser surface texturing (LST) process, a 10 mm thick copper plate is used as a substrate to be engraved. The dimensions of the samples are shown in Figure 1. The samples were cut from a larger copper plate using a shearing/cutting machine. The samples were then ground, polished, and cleaned before undergoing the laser surface texturing process. A fiber laser marking machine was used to conduct the laser surface texturing process in this research. The fiber laser had a 1064 nm wavelength, 300 kHz frequency, and a beam diameter of 50 microns. To measure the width of the grooves, optical microscopy was performed, and ImageJ was used for image analysis and measurements. Thereafter, the water contact angle (WCA) was measured by a wettability test using a SI-CAM contact angle goniometer. Finally, the LEXT OLS5000 laser confocal scanning microscope was employed to characterize the rough surface of the texture samples.

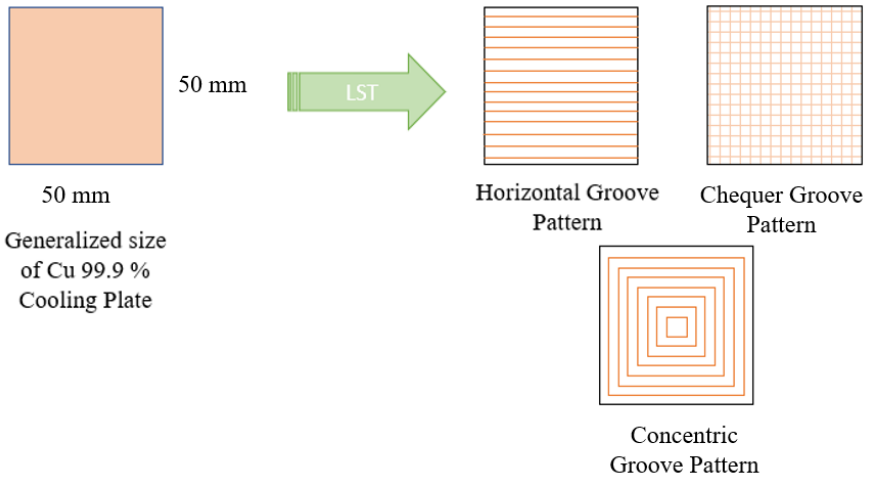

Fig. 1. Schematic showing copper sample dimensions as well as different groove texture patterns created using laser surface texturing (LST).

To determine the thermal performance, hot plate tests were conducted. CJJ78-1 hot plate equipped with magnetic stirring function is used to produce heat. In these tests, the Data Acquisition (DAQ) comprises a measurement system and a computer that enables the temperature sensor system to read and record temperature readings. Note that the temperature data can be monitored and recorded using NI-MAX software on the computer. Figure 2 illustrates the construction of the electrical CPU cooling system used in this experimental simulation. To enhance the heat conduction between the hot plate and heat sinks, 2 ml of generic thermal paste was applied to both sides of the cooling plate. The hot plate serves as the heated CPU in this experimental simulation, and thermal paste is applied as an intermediate layer between the hot plate and the cooling plate, as well as between the cooling plate and the heat sink. Comparing the temperatures at the hot plate (T1), cooling plate (T2), and fins (T3), which will be our outcome to discuss in the results section.

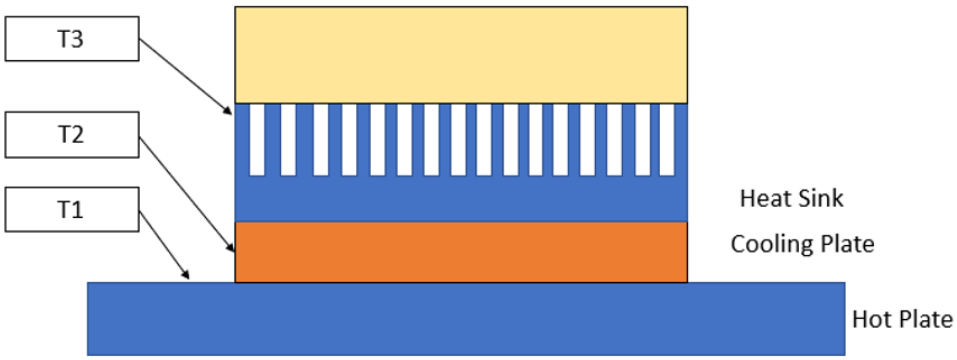

Fig. 2. Schematic showing the experimental simulation of the CPU cooling system.

3 Results and Discussion

3.1 Surface texture groove width

Grooves were engraved using a 30W fiber laser marking machine, utilizing the parameters specified in Table 1. Optical microscopy was employed to monitor the groove. Three grooves were selected from each sample for measurements and analyses using the ImageJ software, as shown in Figure 3. In this test, the largest average width measurement was 90.67 mm for sample 17, while the smallest width measurement was 52.33 mm for sample 13.

Table 1. Summary of the type of samples and the laser surface texturing parameters.

Pattern	Power (%)	Looping Numbers	Hatching Dist. (mm)	Samples ID	Width 1 (μm)	Width 2 (μm)	Width 3 (μm)	Width Avg (μm)
Horizontal line	70	10	0.2	sample 1	77	77	77	77
	90	10	0.2	sample 2	95	86	86	89
	70	10	0.4	sample 3	65	65	65	65
	90	10	0.4	sample 4	79	81	79	79.67
	70	20	0.2	sample 5	70	70	72	70.67
	90	20	0.2	sample 6	70	76	70	72
	70	20	0.4	sample 7	63	59	58	60
	90	20	0.4	sample 8	84	81	81	82
Chequer	70	10	0.2	sample 9	69	58	58	61.67
	90	10	0.2	sample 10	67	67	67	67
	70	10	0.4	sample 11	63	63	63	63
	90	10	0.4	sample 12	77	81	77	78.33
	70	20	0.2	sample 13	53	51	53	52.33
	90	20	0.2	sample 14	51	53	56	53.33
	70	20	0.4	sample 15	65	63	65	64.33
	90	20	0.4	sample 16	91	86	88	88.33
Concentric	70	10	0.2	sample 17	91	88	93	90.67
	90	10	0.2	sample 18	91	86	88	88.33
	70	10	0.4	sample 19	77	81	74	77.33
	90	10	0.4	sample 20	91	84	86	87
	70	20	0.2	sample 21	84	86	80	83.33
	90	20	0.2	sample 22	74	70	72	72
	70	20	0.4	sample 23	73	77	74	74.67
	90	20	0.4	sample 24	88	91	91	90

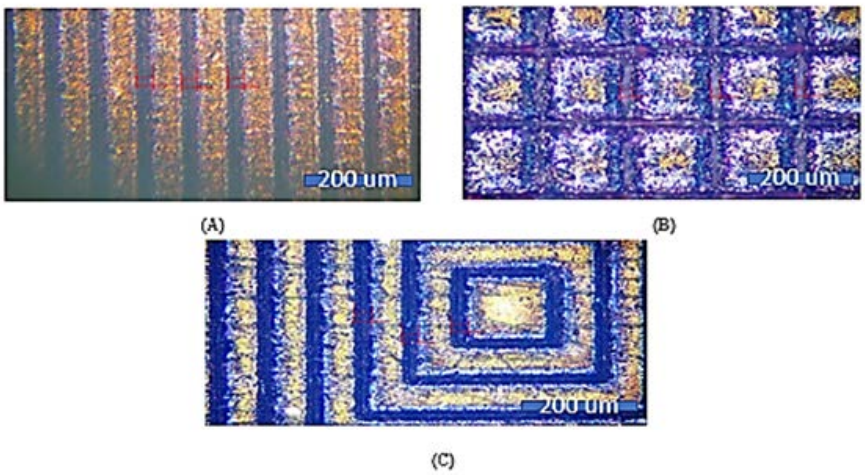

Fig. 3. Optical microscopy images showing the groove for (a) samples 1, (b) samples 9 and (c) samples 18.

Among the samples with a horizontal line pattern, the widest groove was observed in sample 2, measuring 89 µm, while the narrowest groove was found in sample 7, measuring 60 µm. For the chequer pattern, sample 16 displayed the widest groove, measuring approximately 88 µm, whereas sample 13 had the narrowest groove, measuring 52.33 µm. In the case of the concentric pattern, sample 17 exhibited the widest groove, measuring 90.67 µm, while sample 22 had the narrowest groove at 72 µm. In a work by Sulaiman et al.[10], similar trend, increasing the power, resulted in an increase in the groove width being observed. However, exceptions were observed in samples 17 and 18, as well as in samples 21 and 22, where a decrease was noted. Moreover, increasing the number of loops led to a decrease in the width of the groove. Similarly, in many cases, an increase in the hatching distance resulted in a decrease in the groove width. Overall, the power, number of loops, and hatching distance are important parameters that can significantly influence the form and characteristics of grooves in laser surface texturing processes. The similar parameter-property relations weren't observed for samples 17, 18, 21, and 22. But it is to be noted that the laser processing parameters do significantly affect the geometry and surface characteristics of the grooves and texture formed.

3.2 Wettability and roughness

Experiments were conducted to investigate how the water wetting contact angle (WCA) varies with the type of pattern and laser parameters used in creating the textures. As shown in Figure 4, all samples with a horizontal line pattern exhibited a hydrophobic WCA range. This was not the case for the Chequer pattern and concentric pattern were few samples exhibited hydrophilic characteristics. For Chequer pattern this was more visible where either the hydrophilic WCA was observed for the laser parameter with minimum power, loops and hatching distance or for the sample with the higher values associated with these parameters. These experiments helped in identifying the samples with the highest WCA (sample 6) and lowest WCA (sample 23). The lowest WCA 9 (71.32°) was termed as LCA, while the highest WCA (133.53°) was named as HCA sample. Figure 5 shows the goniometer images for the samples in addition to the WCA (68.02°) of the untextured sample. Although it is to be noted

that the majority of the samples exhibited WCA exceeding 90°, indicating their surface nature as hydrophobic wettability.

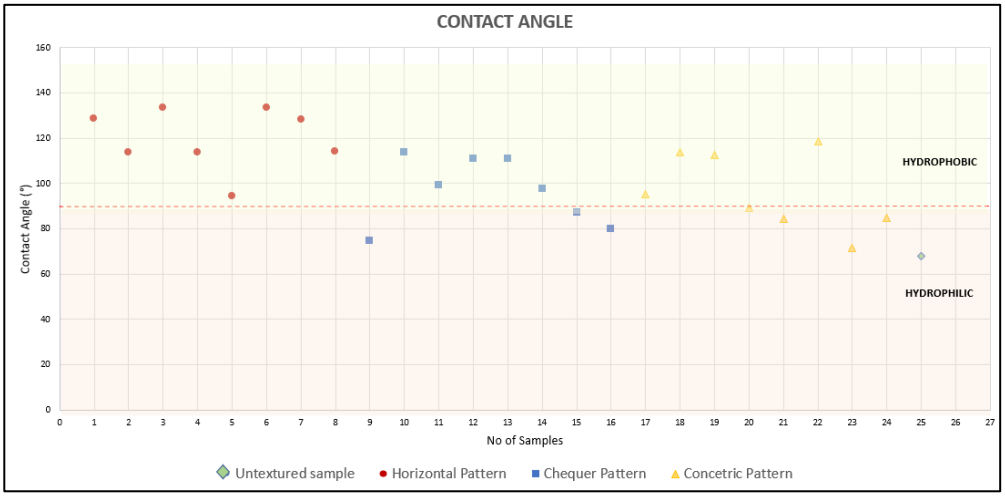

Fig. 4. Scatter plot of the measured contact angles for various samples, indicating the effect of different patterns on wettability.

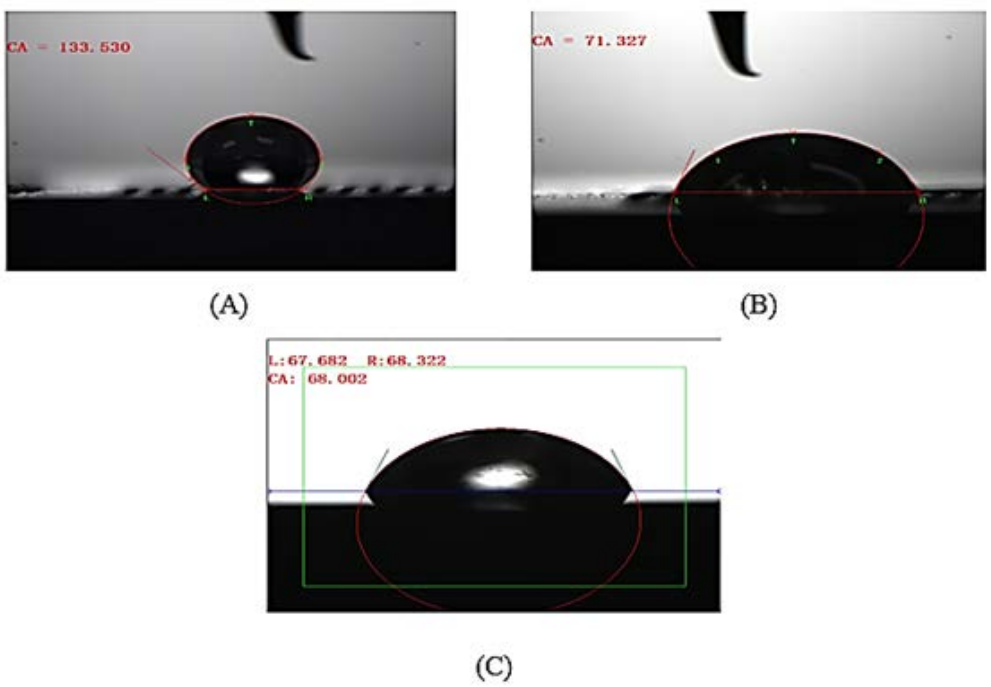

Fig. 5. The goniometer images and corresponding contact angles for (a) sample 6, (b) sample 23, and (c) the control untextured sample.

The surface roughness details for the HCA and LCA provided in Figure 6 were obtained by 3D laser confocal scanning microscopy. The roughness parameters, such as Ra (arithmetic

average roughness), Rq (root mean square roughness), Rz (mean roughness depth), Rsk (skewness), and Rku (kurtosis), were measured. In terms of Ra, the HCA sample (12.68µm) exhibited 22.7 % lower values than the LCA sample (16.39µm). In terms of Rz, the HCA (51.8 µm) has 50.3% lower values than LCA (104.175 µm). The HCA (15.18 µm) sample also exhibited a 25.6% lower Rq (20.134 µm) than the LCA. HCA sample (1.22µm) showed higher Rsk than LCA (0.074µm) and HCA sample (2.88µm) exhibited 13.25 % higher Rku than the LCA sample (2.55µm). The general roughness parameters do not take into account the characteristics of the surface texture shape, but Rsk and Rku do include the asymmetry and sharpness or peak surface height distribution. As can be observed in Figure 6(a) for HCA, there are sharp peaks distributed throughout the measurement surface. The HCA sample has more and stronger peaks than the LCA samples, signifying a higher Rku. The hydrophobic surface in HCA is governed by more shape and extreme texture compared to the hydrophobic in Figure 6(b), which supports that air trap could occur in the void space of deep valleys. There are more caps or pillars observed in Figure 6(a) that could prevent water droplet from penetrating the surface. This can correlate to Cassie-Baxter state of wettability as reported by Zul et al. [11]. But it is important to note that several other factors also contribute to the surface wettability such as the geometry of the texture (re-entrant or overhang), etc.

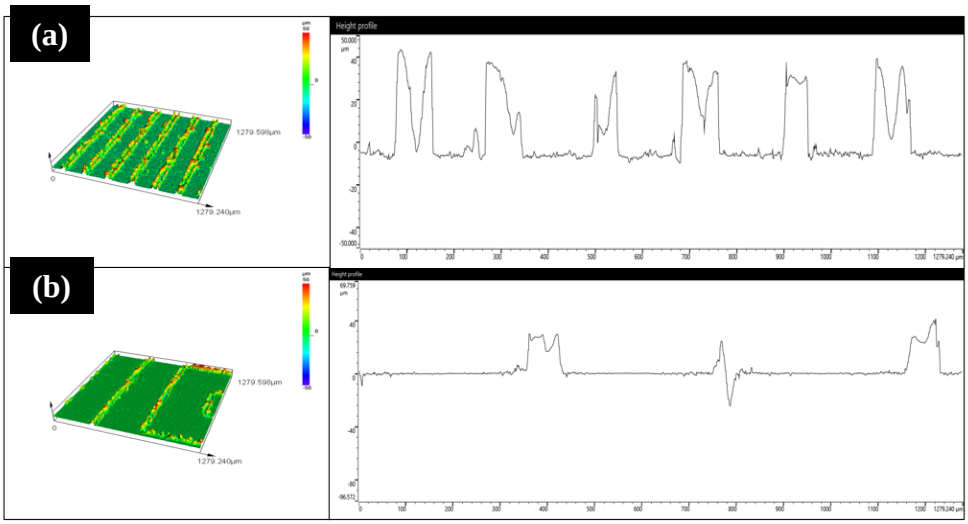

Fig. 6. 3D laser confocal scanning microscopy data show the height profiles for (a) sample 6 and (b) sample 23.

3.3 Temperature profile

With the Aid of thermocouples, the temperature profile was recorded for the cooling plate (T2) and the heatsink (T3) to simulate the electronic CPU cooling system. The temperature profiles were recorded for the untextured, LCA (sample 23), and HCA (sample 6) and are presented in Figure 7. It can be observed that the LCA recorded the highest temperature of 95.3 °C, reaching within the experiment time period of 240 seconds. This was followed by HCA (94°C) and untextured sample (93.7°C) signifying that the LCA and HCA sample would result in greater heat transfer from the hot plate heat source and transmit it to the heat sink. Although the WCA of the untextured sample is lower than the LCA sample, the lower WCA did not necessarily contribute to the higher T_{max} recorded. The T_{max} temperature did not entirely depend on the WCA, but other factors such as surface roughness, increase in surface area, in addition to groove dimension, might have affected the heat transfer

characteristics. As the heat travels from the cooling plate towards the fins, a lower temperature would be preferred at the fin tip. This is also observed in our case for the laser-textured samples, as shown in Figure 7(b), in which the untextured sample shows a higher heat sink temperature when compared with the HCA and LCA samples. In the case of the fins (T3), the performance of the HCA and LCA seems to coincide with little variation in the temperature profile curve.

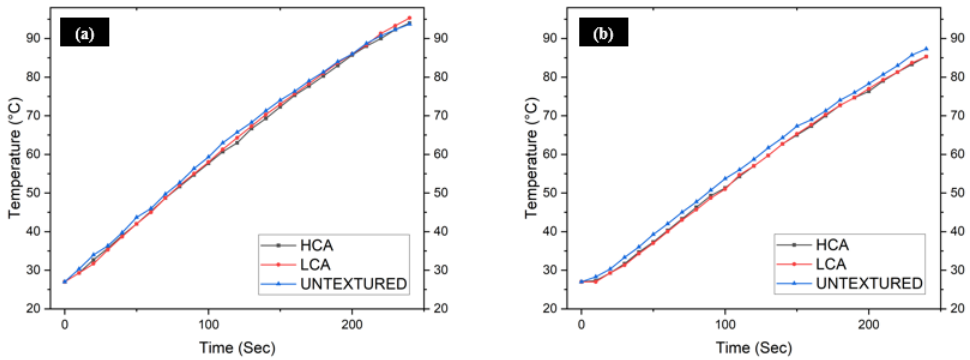

Fig. 7. Temperature profiles of (a) the cooling plate (T2) and (b) the fins (T3).

4 Conclusion

In this work, the effect of laser surface texturing on the temperature profiles of the cooling plates of CPU heat sinks found in common desktop computers was investigated. Different laser texturing parameters and various shapes of the textures produced on the samples exhibited either a high wetting contact angle (HCA), indicating hydrophobicity, or a low wetting contact angle (LCA), indicating hydrophilicity. Thereafter, the roughness of these samples was evaluated. The following conclusion can be drawn from this study.

1. The surface roughness changes as the laser parameters and texture patterns produce different groove dimensions and texture pitch.
2. The HCA sample was characterized by a higher RSK/RKU roughness profile that achieved a WCA of 133.53° with an arithmetic roughness Ra of 12.684 µm
3. The LCA samples exhibited an Ra of 16.399 µm with a WCA of 71.327°.
4. The impact of HCA and LCA on the temperature profile showed a temperature difference of 2°C at T2, the cooling plate, with T3 fin temperature when compared with the performance of the untextured sample.
5. The difference between the heat transfer performance of the HCA and LCA samples was not pronounced, but they both performed better than the untreated samples.

Although the reduction in temperature appears to be nominal, the 2 °C difference should provide a critical threshold between stable CPU performance and thermal throttling. This could impact system speed and performance in the long run, particularly when running resource-intensive system applications. Additional research in this field could further expand the boundaries of temperature difference, directly contributing to the development of cooler and more efficient heat transfer systems produced with the aid of the laser surface texturing technique.

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