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# Temperature Control with a Thermoelectric Cooler (TEC) during Laser Decapsulation of Plastic Packages

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**Abstract** – Ablation was carried out on high voltage Schottky rectifiers at 25°C and -5°C (with a thermoelectric cooler or TEC), at 1.0 W and 3.9 W of laser power. *In-situ* measurement of the reverse current was conducted and correlated to the device junction temperature. It was found that the usage of a TEC increases the number of laser scans to reach the set current compliance of 100  $\mu\text{A}$  after exposing the die, for ablation at 3.9 W, although eventual damage to the device is still unavoidable. The incorporation of a TEC below the sample is also demonstrated to be effective in reducing the device junction temperature during laser ablation.

## I. INTRODUCTION

With the continual shrinking of devices and the introduction of new materials such as copper bond wires [1], chemical, mechanical and plasma decapsulation [2] have nearly reached their limits. For instance, chemical decapsulation may damage the copper bond wires, the die or interconnections, since it is isotropic in nature [3, 4].

Laser decapsulation is a promising failure analysis (FA) technique, which works with high speed and precision. Besides, it minimizes the effects of corrosion and overetching of leadframes [2-4]. Apart from being able to alleviate some of the problems of chemical, mechanical and plasma decapsulation, laser decapsulation is not constrained by geometry and it provides a good selectivity of plastic ablation over metals [5].

However, laser decapsulation may cause thermal stresses [2], damages to metallization or passivation [4], and thermal elevation or electrostatic damages (ESD) [6] to devices. Therefore, the aim of this work is to investigate the effectiveness of incorporating a thermoelectric cooler (TEC) on a cooling plate below the sample during laser ablation to reduce the thermal effects.

## II. EXPERIMENTAL DETAILS

### A. Experimental Setup

The laser decapsulation system used in this project is the Sesame 1000 from Digit Concept, with a Nd:YAG laser (1064 nm) and a maximum power of 10 W. The sample is a high voltage power Schottky rectifier STPS80170C comprising two diodes, as shown in Fig. 1.

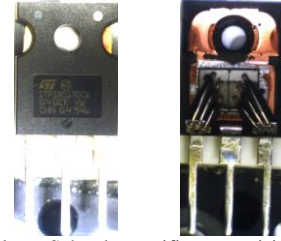


Fig. 1. High voltage Schottky rectifier comprising two diodes.

Figure 2 shows the linear relationship between the reverse current and the junction temperature of one of the two diodes at an applied reverse voltage of 100 V, which was re-plotted from the graph of reverse leakage current versus applied reverse voltage (per diode), from the sample data sheet [7].

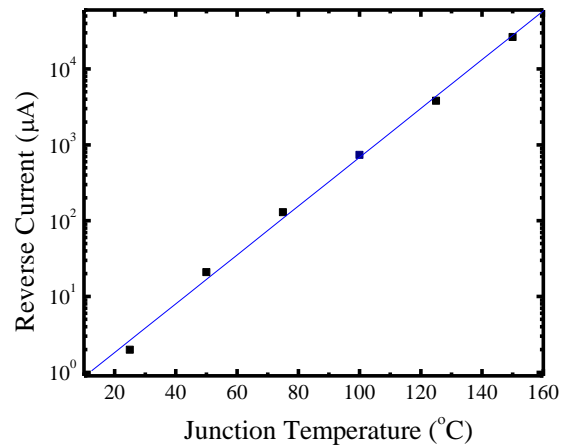


Fig. 2. Graph of reverse current vs junction temperature at an applied reverse voltage of 100 V for one diode.

The relationship of the reverse current versus junction temperature at an applied reverse voltage of 100 V is obtained by a linear fit as given in Equation (1).

$$\text{Log } I_r = -0.0383 + 0.0322T. \quad (1)$$

where  $I_r$  is the reverse current and  $T$  is the junction temperature in °C.

In order to understand the relationship between the reverse current and the junction temperature of the device during laser ablation, measurement of the reverse current was done *in-situ* using a Keithley 2400 source meter and Agilent 34401A multimeters. The experiments were carried out at an applied reverse voltage of 100 V.

Each time, one diode was subjected to an applied reverse voltage of 100 V. The reverse current was measured over time and correlated to the device junction temperature using Fig. 2.

Decapsulation was carried out at 25°C and -5°C, and at 1.0 W and 3.9 W of laser power. For ablation at -5°C, the sample was held with ice on a TEC mounted and glued onto a cooling plate as shown in Fig. 3. A platinum thin film Pt100 resistance temperature detector (RTD) and a thermoelectric temperature controller LFI-3751 with autotune function were also used for the experiments. Prior to and after the laser ablation, the reverse current versus reverse voltage ( $I_r$ - $V_r$ ) was measured for every sample at 25°C.

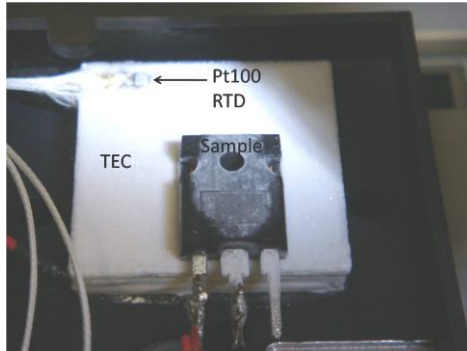


Fig. 3. Sample held with ice on a TEC mounted and glued onto a cooling plate.

#### B. Determining the number of scans for decapsulation

To determine the number of scans for decapsulation for each laser power, samples were ablated at 25°C under two conditions: (i) 5 s interval scans and (ii) continuous scans till the set current compliance of 100  $\mu$ A was reached. The first scan was performed at time 50 s. For 5 s interval scans,  $I_r$ - $V_r$  measurements were taken after the 10<sup>th</sup>, 20<sup>th</sup>, 30<sup>th</sup>, 35<sup>th</sup> scans and every scan after the 35<sup>th</sup> scan till compliance. Performing the 5 s interval scans till compliance aided in determining the number of scans for continuous ablation and also the number of scans to expose the die, which was difficult to observe under continuous ablation. All  $I_r$ - $V_r$  measurements were done at 25°C.

Fig. 4 shows the  $I_r$ - $V_r$  curves for ablation at 25°C, 1.0 W of laser power, at 5 s interval scans till compliance and Fig. 5 shows the graph of reverse current versus time ( $I_r$ -t) under continuous scans till compliance.

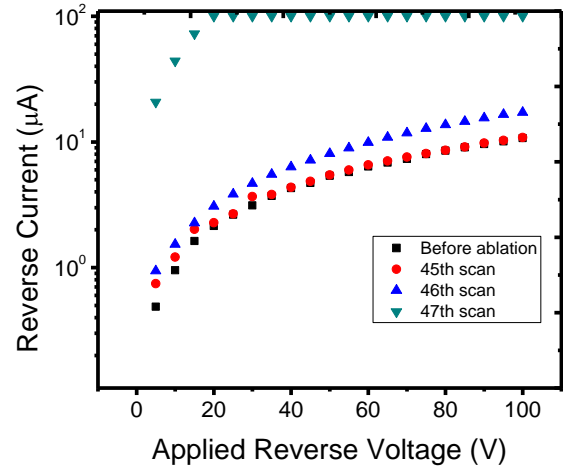


Fig. 4.  $I_r$ - $V_r$  curves for ablation at 25°C, 1.0 W, 5 s interval scans till compliance.

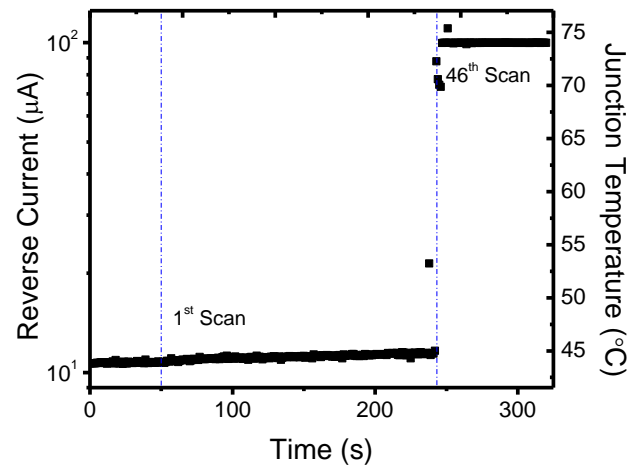


Fig. 5.  $I_r$ -t curve for ablation at 25°C, 1.0 W, under continuous scans till compliance.

On the other hand, Fig. 6 shows the  $I_r$ - $V_r$  curves for ablation at 25°C, 3.9 W of laser power, at 5 s interval scans till compliance and Fig. 7 shows the  $I_r$ -t graph under continuous scans till compliance.

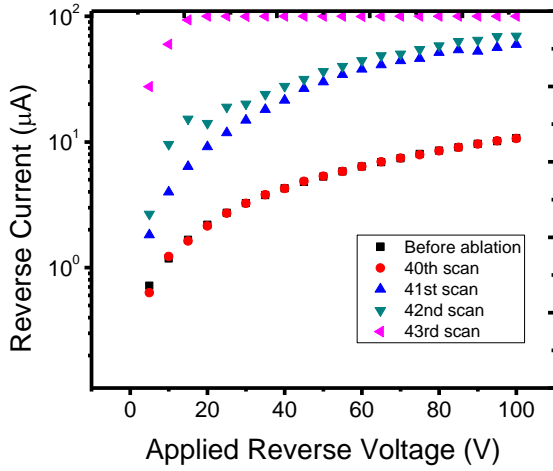


Fig. 6.  $I_r$ - $V_r$  curves for ablation at 25°C, 3.9 W, 5 s interval scans till compliance.

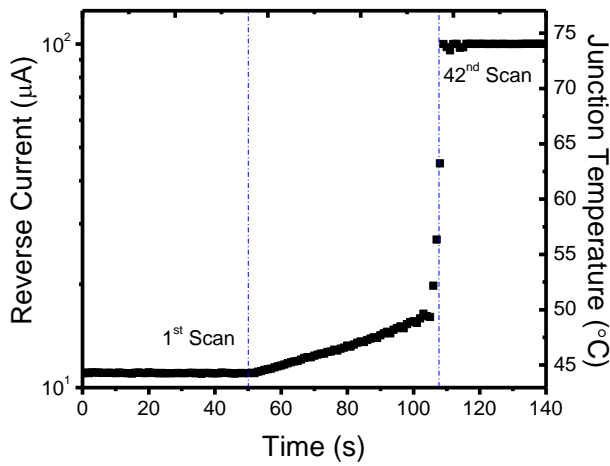


Fig. 7.  $I_r$ - $t$  curve for ablation at 25°C, 3.9 W, under continuous scans till compliance.

A summary on the number of scans for ablation at 25°C at 1.0 W and 3.9 W, at 5 s interval scans and under continuous scans till compliance is shown in Table 1.

Table 1. Summary on the number of scans for ablation at 25°C at 1.0 W and 3.9 W, at 5 s interval scans and under continuous scans till compliance.

	Laser Power	
	1.0 W	3.9 W
No. of scans at 5 s interval scans to reach die	44	40
No. of scans at 5 s interval scans to reach compliance	47	43
No. of continuous scans to reach compliance	46	42

From Table 1, for ablation at 5 s interval scans, the die was exposed at the 44<sup>th</sup> scan at 1.0 W and 40<sup>th</sup> scan at 3.9 W. The number of scans to reach compliance at 1.0 W and 3.9 W was 47 and 43, respectively. For continuous ablation, the number of

continuous scans to reach compliance was 46 and 42, for 1.0 W and 3.9 W of laser power, respectively. Fewer scans were needed to reach the die and compliance at 3.9 W than 1.0 W of laser power, since 3.9 W generates much more thermal heat, contributing to a faster rate of ablation.

Comparing ablation at 5 s interval scans and ablation under continuous scans, more scans were needed to reach compliance at 5 s interval scans. The 5 s interval scans allowed a longer cooling period for the sample in between scans during laser ablation. Hence, compliance was reached later.

It was decided that the laser ablation be stopped near to the diode, but not exposing or damaging the diode, which would cause an abrupt increase in the reverse current. Hence, 35 continuous scans were performed for laser ablation of each sample.

### C. Effectiveness of using a TEC

In order to investigate whether the TEC can reduce or delay the damage of the diode, ablation was carried out at -5°C (TEC) at 3.9 W of laser power. Fig. 8 shows the  $I_r$ - $V_r$  curves for ablation at -5°C (TEC), 3.9 W, at 5 s interval scans till compliance and Fig. 9 shows the  $I_r$ - $t$  graph under continuous scans till compliance. All  $I_r$ - $V_r$  measurements were done at -5°C (TEC).

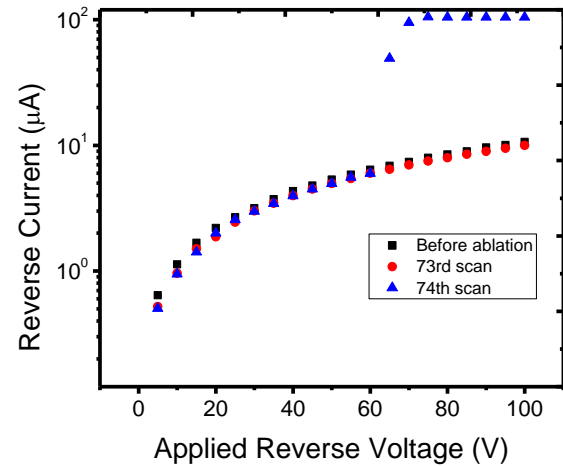


Fig. 8.  $I_r$ - $V_r$  curves for ablation at -5°C (TEC), 3.9 W, 5 s interval scans till compliance.

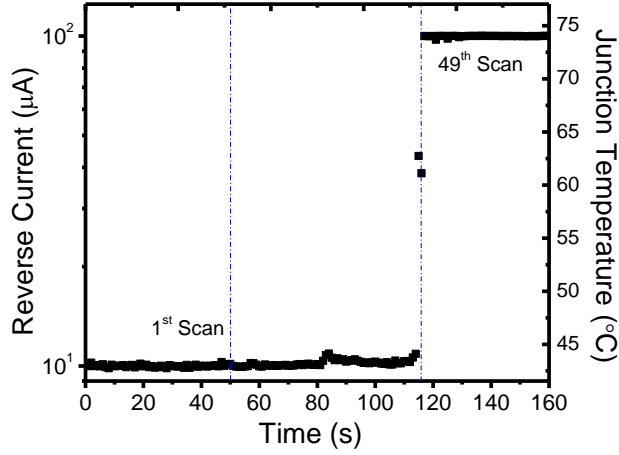


Fig. 9.  $I_r$ -t curve for ablation at  $-5^\circ\text{C}$  (TEC), 3.9 W, under continuous scans till compliance.

A comparison of the number of scans to reach the die and to reach compliance at 5 s interval scans, and the number of scans to reach compliance under continuous scans, for ablation at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC), at 3.9 W, is shown in Table 2.

Table 2. Comparison of the number of scans to reach the die and to reach compliance at 5 s interval scans, and the number of scans to reach compliance under continuous scans, for ablation at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC), at 3.9 W.

	$25^\circ\text{C}$	$-5^\circ\text{C}$ (TEC)
No. of scans at 5 s interval scans to reach die	40	46
No. of scans at 5 s interval scans to reach compliance	43	74
No. of continuous scans to reach compliance	42	49

From Table 2, for ablation at 5 s interval scans, the die was exposed at the 40<sup>th</sup> and 46<sup>th</sup> scan at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC), respectively. Compliance occurred at the 43<sup>rd</sup> scan at  $25^\circ\text{C}$  and 74<sup>th</sup> scan at  $-5^\circ\text{C}$  (TEC). By incorporating a TEC during laser ablation at  $-5^\circ\text{C}$ , almost twice the number of scans and a longer time were needed for ablation, compared to ablation at  $25^\circ\text{C}$ . This is due to the TEC in reducing the rate of ablation. Although the usage of a TEC increases the number of laser scans to reach compliance after exposing the die, eventual damage to the device is still unavoidable.

#### D. Ablation at $25^\circ\text{C}$ and $-5^\circ\text{C}$ (TEC) at 1.0 W and 3.9 W

Ablation was carried out at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC) for each laser power, to study if incorporating a TEC can effectively reduce the thermal heat induced in the device during laser ablation. A total of 35 continuous scans were carried out on each sample, of which, the first scan was performed at time 50 s. Fig. 10 and Fig. 11 show the  $I_r$ -t graphs for ablation at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC), at 1.0 W and 3.9 W, respectively. Table 3 summarizes the maximum junction temperatures and maximum temperature

increase of samples ablated at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC), at 1.0 W and 3.9 W.

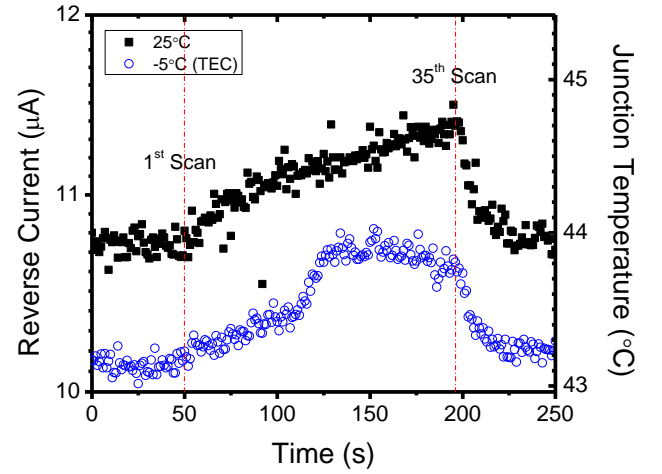


Fig. 10.  $I_r$ -t curves for ablation at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC) at 1.0 W.

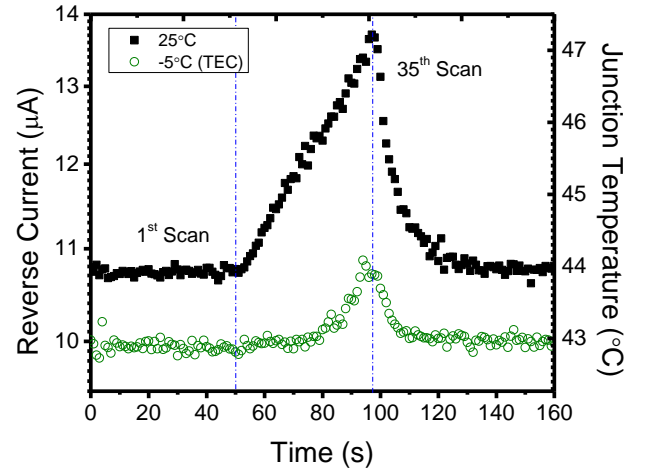


Fig. 11.  $I_r$ -t curves for ablation at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC) at 3.9 W.

Table 3. Maximum junction temperatures and maximum temperature increase of samples ablated at  $25^\circ\text{C}$  and  $-5^\circ\text{C}$  (TEC) at 1.0 W and 3.9 W.

	$25^\circ\text{C}$	$-5^\circ\text{C}$ (TEC)
Max. junction temperature for ablation at 1.0 W ( $^\circ\text{C}$ )	44.8	43.9
Max. junction temperature for ablation at 3.9 W ( $^\circ\text{C}$ )	47.3	44.1
Max. temperature increase at 1.0 W ( $^\circ\text{C}$ )	0.95	0.85
Max. temperature increase at 3.9 W ( $^\circ\text{C}$ )	3.50	1.30

From Table 3, the maximum junction temperature of the diode was about  $44.8^\circ\text{C}$  (without TEC), but  $43.9^\circ\text{C}$  (with TEC), for ablation at 1.0 W. For ablation at 3.9 W, the maximum junction temperature of the diode was about  $47.3^\circ\text{C}$  (without

TEC), but 44.1°C (with TEC). The  $I_r$ - $V_r$  curves at 25°C and -5°C (TEC) are the same before and after ablation, which suggests that the diode was still working after ablation. Thus, with a TEC, the junction temperature of the diode was reduced by 0.9°C (2.01%) for ablation at 1.0 W and reduced by 3.2°C (6.77%) for ablation at 3.9 W, during ablation at -5°C.

If we compare the maximum junction temperatures for ablation at 1.0 W and 3.9 W at 25°C without the TEC, the value for 3.9 W was higher by 2.5°C (5.29%) than that for 1.0 W. This is due to the 3.9 W of laser power being able to induce more heat in the sample, and thus contribute to the higher reverse current and maximum junction temperature. For ablation at -5°C (TEC), the difference in maximum junction temperatures for ablation at 1.0 W and 3.9 W was only 0.2°C (0.454%), suggesting that the TEC may be equally effective in reducing the maximum junction temperatures for both ablation at 1.0 W and 3.9 W at -5°C, as reflected in the maximum temperature increase in Table 3.

To understand the phenomenon occurring during laser ablation, the reverse current was extrapolated and plotted against the number of scans, as shown in Fig. 12 and Fig. 13, for ablation at 25°C and -5°C (TEC), at 1.0 W and 3.9 W, respectively.

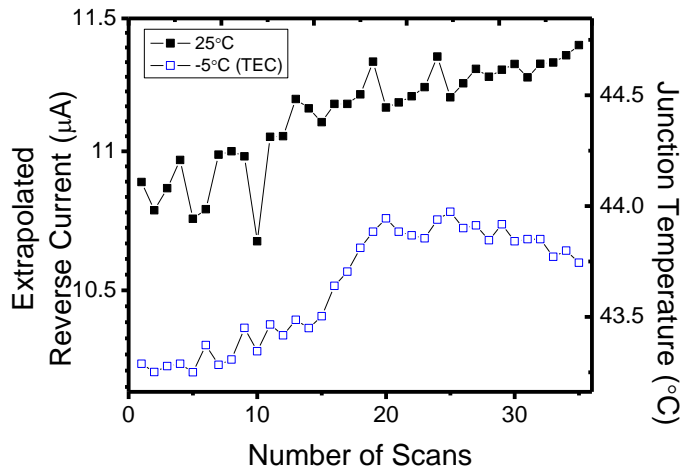


Fig. 12. Extrapolated reverse current vs the number of scans for ablation at 25°C and -5°C (TEC), at 1.0 W.

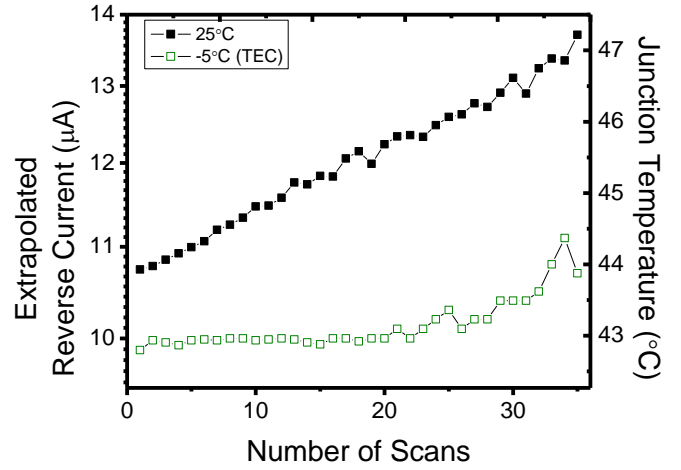


Fig. 13. Extrapolated reverse current vs the number of scans for ablation at 25°C and -5°C (TEC), at 3.9 W.

From Fig. 12 and Fig. 13, for ablation at 25°C, the reverse current increased more steeply for ablation at 3.9 W than at 1.0 W. This is due to the higher laser power at 3.9 W generating much more heat, thus the rise in reverse currents and junction temperatures were higher.

Ablation at -5°C (TEC) has been shown to decrease the reverse currents and junction temperatures, compared to ablation at 25°C for both 1.0 W and 3.9 W. For ablation at 1.0 W, there was an increase in the reverse current starting from the 15<sup>th</sup> scan, which was when the bond wires had been exposed. The reverse current and junction temperature increased after the 15<sup>th</sup> scan, followed by a plateau (20<sup>th</sup> – 35<sup>th</sup> scans). This plateau may suggest that the TEC was able to suppress the junction temperature to around 44°C, from the moment the bond wires were exposed till the end of the 35 continuous scans. Furthermore, the existence of the plateau may be due to the lower laser power inducing less heat in the device during ablation, and enabling the heat to dissipate through the heat sink of the samples over the number of scans.

On the other hand, for ablation at 3.9 W, the increase in the reverse current and junction temperature was gradual from the first scan to the 22<sup>nd</sup> scan and became more pronounced after the 31<sup>st</sup> scan. This may be due to the TEC not being able to cool the sample fast enough during ablation, therefore causing a higher increase in the reverse current and junction temperature.

In short, the TEC was able to suppress and maintain the maximum junction temperature from the moment the bond wires were exposed till the end of the 35 scans, for ablation at 1.0 W. However, for ablation at 3.9 W, the TEC might not be able to cool the sample fast enough during ablation, thus resulting in a higher increase in the reverse current and junction temperature.

### III. CONSIDERATIONS AND LIMITATIONS OF TEC SETUP

During the course of the experiments, there were some variations in the measurements and these were found to be due to the setup of the TEC. The following are some considerations that have to be noted for the proper setup of the TEC:

- i. applying only one drop of water or less onto the TEC and wiping off any excess water or condensation on the TEC before carrying out the experiments, to limit the contribution to resistive paths during ablation which melts the ice above the samples and affects the experimental results;
- ii. positioning the sample near the edge of the TEC to limit the contribution to resistive paths from the leads of the sample when the ice on the leads melts; and also positioning of the TEC setup with the Pt100 RTD away from the vacuum, to limit fluctuations in experimental measurements;
- iii. ensuring that the Pt100 RTD is glued properly to the TEC and the TEC is adhered well onto the cooling plate, in order to reach the set temperature for the TEC and prevent damage to the RTD and the TEC.

The limitations of the TEC setup include the difficulty in carrying out ablation at temperatures such as  $-1^{\circ}\text{C}$  to  $-3^{\circ}\text{C}$ , as the ice above the sample tends to melt and contribute to resistive paths when the bond wires start to expose. The TEC controller has a compliance voltage of 8 V, where temperatures much lower than  $-5^{\circ}\text{C}$  are difficult to achieve, as the thermoelectric voltage has reached the compliance value.

### IV. CONCLUSION

Ablation was carried out on high voltage Schottky rectifiers at  $25^{\circ}\text{C}$  and  $-5^{\circ}\text{C}$  (TEC) with 1.0 W and 3.9 W of laser power, at (i) 5 s interval scans and (ii) continuous scans till the set current compliance of 100  $\mu\text{A}$ , in determining the number of scans needed to reach compliance. By incorporating a TEC during laser ablation at  $-5^{\circ}\text{C}$  at 3.9 W, almost twice the number of scans and a longer time were needed for ablation, compared to ablation at  $25^{\circ}\text{C}$ , 3.9 W. This is due to the TEC in reducing the rate of ablation. Although the usage of a TEC increases the number of laser scans to reach compliance after exposing the die, eventual damage to the device is still unavoidable.

Ablation was also carried out at  $25^{\circ}\text{C}$  and  $-5^{\circ}\text{C}$  (TEC) for each laser power, to study if incorporating a TEC can effectively reduce the thermal heat induced in the device during laser ablation. With a TEC, the junction temperature of the diode was reduced by  $0.9^{\circ}\text{C}$  (2.01%) for ablation at 1.0 W and reduced by  $3.2^{\circ}\text{C}$  (6.77%) for ablation at 3.9 W, during ablation at  $-5^{\circ}\text{C}$ . Comparing the maximum junction temperatures for ablation at 1.0 W and 3.9 W at  $25^{\circ}\text{C}$ , the value for 3.9 W was higher by  $2.5^{\circ}\text{C}$  (5.29%) than that for 1.0 W. This is due to the 3.9 W of

laser power being able to generate much more heat, and thus contribute to the higher reverse current and maximum junction temperature. However, for ablation at  $-5^{\circ}\text{C}$  (TEC), the difference in maximum junction temperatures for ablation at 1.0 W and 3.9 W was only  $0.2^{\circ}\text{C}$  (0.454%), suggesting that the TEC may be equally effective in reducing the maximum junction temperatures for both ablation at 1.0 W and 3.9 W at  $-5^{\circ}\text{C}$ .

By extrapolating the reverse current and plotting it against the number of scans for ablation at  $25^{\circ}\text{C}$  and  $-5^{\circ}\text{C}$  (TEC), at 1.0 W and 3.9 W, it was discovered that for ablation at 1.0 W, the reverse current and junction temperature increased after the 15<sup>th</sup> scan, followed by a plateau (20<sup>th</sup> – 35<sup>th</sup> scans). The TEC might be able to suppress and maintain the maximum junction temperature for ablation at 1.0 W, due to the lower laser power generating less heat. However, for ablation at 3.9 W, the TEC might not be able to cool the sample fast enough during ablation, thus resulting in a higher increase in the reverse current and junction temperature.

The incorporation of a TEC below a sample is also demonstrated to be effective in reducing the device junction temperature during laser ablation. It is hoped that this improvement can reduce the thermal elevation of devices sensitive to temperature increase during the laser decapsulation process.

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