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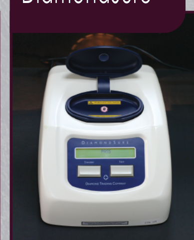

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Damage caused to Gemstones by Lasers during Jewellery Repair
珠寶維修期間激光對寶石造成的損壞


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由於激光光束狹窄且聚焦，在珠寶維修時它可以精確定位焊點或焊縫，而不會對周圍環境產生太多熱傳導，從而避免需要卸下所有寶石，卻又能將對寶石的損壞風險降至最低。儘管有聲稱珠寶維修所採用的激光不會傷害已鑲嵌的寶石，但不時發佈的報告卻記錄了此類激光對已鑲嵌的寶石造成明顯的損害。最近，一些寶石鑑定所觀察到珠寶維修的激光對有色寶石造成損壞；其中一些損壞發生在高價值寶石上，例如克什米爾藍寶石和緬甸、東非、泰國紅寶石等。如果這些寶石因此類損壞而必須重新研磨拋光，寶石將會失去相當大的重量，影響其價值。

Introduction

Since the early 1990s, lasers have become increasingly popular not only in the advanced instrumentation of gem labs but also for jewellery repair (Weldon, 1992). The enormous advantage of these commercial laser systems is that a bench jeweller can make delicate repairs to jewellery set with heat-sensitive materials without having to unmount all the gems. Because the laser's beam is narrow and focused, it can make pinpoint solder joints or welds without much heat conduction to the surrounding setting, which minimizes the risk of damage (Misiorowski, 2000; Wade 2002).

Despite the claims that the jewellery repair laser doesn't harm mounted gemstones, reports have been published from time to time that document damage obviously caused by such lasers (Hänni, 2009), and online discussions mentioning damage to diamonds and coloured gemstones date back as far as 2002 (https://orchid.ganoksin.com/t/laser-welding/16491).

Recently, several gem labs have observed damage to coloured gemstones caused by a repair laser (SSEF, 2019; Kiefert & Schollenbruch, 2019). Some of this damage has occurred on high-value gemstones such as Kashmir sapphires (Fig. 1) and Burmese (Myanmar sapphires), East African and Thai rubies. If these gems have to be repolished due to such damage, they lose considerable weight and therefore value.

Fig. 1 Kashmir sapphire of 5.11 cts (table and pavilion side) submitted by a client showing several deep areas of laser damage along the girdle and on the pavilion, even visible with the naked eye through the crown.
Photo: M.S. Krzemnicki, SSEF
客戶提交的 5.11 cts克什米爾藍寶石（檯面和亭側），顯示了沿著腰圍和亭部的幾個深層激光損傷區域，甚至可以通過冠部用肉眼觀察到。

In order to investigate the actual damage a commercial jewellery repair laser may produce, a range of coloured gemstones of various quality was selected and these were exposed to a commercial laser used in a professional workshop for jewellery repairs. The results of this experiment are presented here.

Fig.2 These gemstones were tested with the jewellery repair laser: from top left to bottom right: one tanzanite, two green tourmalines, three sapphires, three rubies, five emeralds and one garnet. *Photo: K. Schollenbruch, GGL.*
這些寶石使用珠寶修復激光進行了測試：從左上到右下：一顆坦桑石、兩顆綠色碧璽、三顆藍寶石、三顆紅寶石、五顆祖母綠和一顆石榴石。

Materials and methods

16 gemstones were selected for this study to cover different mineral species as well as different clarity grades in order to evaluate the effect of the laser on these gems. Fig. 2 gives an overview of the tested gemstones (sapphire, ruby, emerald, garnet, tourmaline, and tanzanite).

For this study we used a commercial laser welder (Alpha Laser A50) equipped with an Nd-YAG laser emitting at 1064 nm with a maximum laser power of 50 W. The working power used for welding is usually about 4.0 W.

Although jewellery pieces are usually handheld during soldering and the laser is focused free hand on the surface, in most cases we used a metal block (adjustable in height) on which the gemstone could rest instead. This sample holder was covered with a leather pad in order to avoid reflections from the metallic surface (Fig. 3).

The gemstones were tested using various energy settings with and without the leather pad as well as hand-held to see if the results varied. Standard setup was on a metal block with a leather pad (Fig. 3) with the laser focused on the surface of the pavilion.

Microscopic images were taken using a GIA DL Scope Pro Trinocular Microscope equipped with a Canon EOS 6D camera.

Fig. 3 Interior of the Alpha Laser A50 chamber. The stone is positioned on a metal block covered with a leather pad to avoid reflection of the laser on the metallic surface.
Photo: L. Kiefert, GGL.
在3 Alpha Laser A50 內部，寶石放置在覆蓋有皮革墊的金屬塊上，以避免激光在金屬表面的反射。

Results

The first sapphire that was tested while hand-held produced a surprising result. The damage appeared on the opposite side of the laser focus in a cone-shaped tube (Fig. 4). A secondary area of damage was recorded at a random location which was also located on the opposite side of the stone.

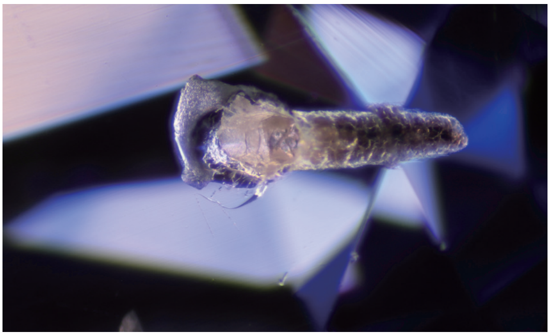

Fig. 4 This cone-shaped tube was caused by a laser focused on the surface opposite the area of damage. *Photo: K. Schollenbruch, GGL.*
這個錐形管是由激光聚焦在損傷區域對面的表面上造成的。

Most tests were performed with an energy of 3.6 to 4.1 W, the usual setting for jewellery welding. The laser beam was focused to a spot diameter of approx. 5 µm. With this laser energy and focus the laser caused damage on all tested samples with various results. It is difficult to estimate the impact of the various factors (such as for example laser energy, focus position, gem species, presence of inclusions) on the resulting damage due to the laser shooting.

Apart from the energy, the pulse, the focus of the laser beam and the backing of the mineral, it seemed that the number of inclusions and the size of the stone also affected the final result. The more fractures that were observed in a stone the shallower the impact was of the laser beam. On stones without fractures the laser left distinct traces which could be used to identify laser damage (Fig. 5).

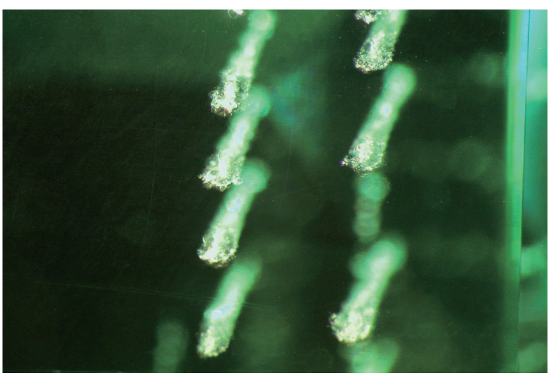

Fig. 5 Series of cone-shaped areas of damage created by a laser (1064 nm emission) in an inclusion-free synthetic green corundum. *Photo: M.S. Krzemnicki, SSEF*
由激光（1064 nm 放射）在不含內含物的合成綠色剛玉中造成的一連串錐形的損傷。

In most cases a shallow to cone-shaped cavity was observed. Often this cavity was either filled or coated with a glassy substance (Fig. 6) resulting from the local melting of the gemstone due to the laser. In some cases, this feature might visually resemble a cavity filled with "aged" resin or lacquer.

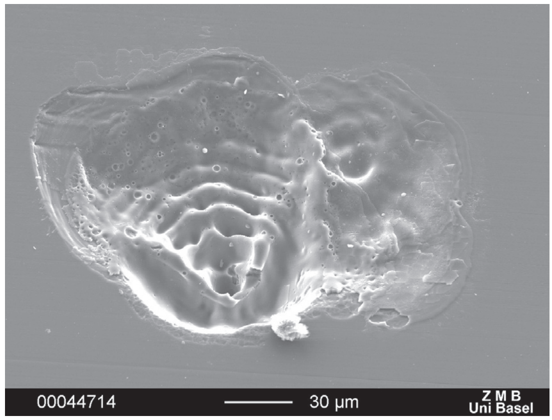

Fig. 6 SEM micrograph (high magnification) of a sapphire surface showing a cone-shaped area of laser damage with deposition of molten material as a glassy residue in the cavity created. *Photo: M.S. Krzemnicki, SSEF and University of Basel.*
藍寶石表面的掃描電子顯微照片（高放大倍數）顯示激光損壞的錐形區域，熔融材料沉積為空腔中的玻璃狀殘留物。

The glassy substance observed in these laser holes often shows a brownish colour and is pervaded by small fissures (crackling) as a result of fast cooling (Fig. 7a), but in some cases it may also have a whitish, foamy appearance due to numerous small microcracks and tiny inclusions (Fig. 7b).

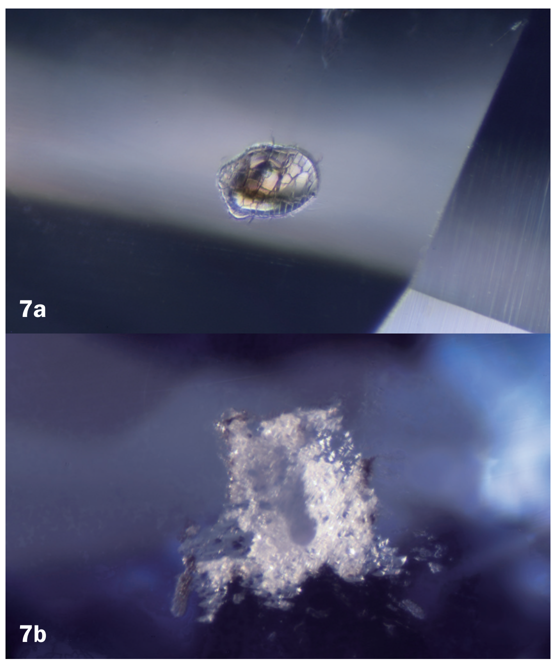

Fig. 7 a) laser spot with brownish glassy crust – crackled. b) whitish, foamy glass residue around the laser hole. *Photos: K. Schollenbruch, GGL.*
a) 帶有褐色玻璃狀外殼的激光點—裂紋。
b) 激光孔周圍的白色泡沫狀玻璃殘留物。

In many cases small chips are splintered from the surface around the hole. In some of the samples, the tension caused during laser treatment lead to the formation of numerous cracks around the laser hole (Fig. 1) or even forced the stone to break as shown in Fig. 8a and 8b.

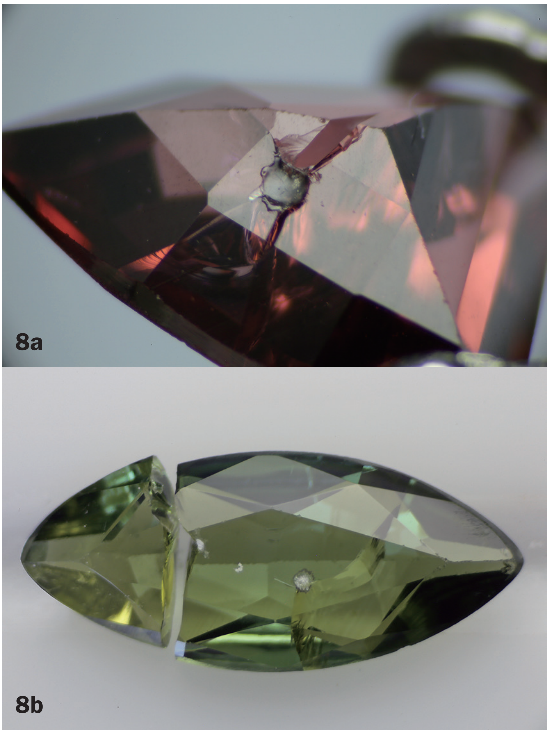

Fig. 8 a) Laser-induced damage on a garnet.
b) This inclusion-free tourmaline broke after the laser hit its surface (The white spot in the centre of the sample was caused by another laser impulse with less energy).
Photos: K. Schollenbruch, GGL.
a) 激光對這石榴石造成的損傷。 b) 這顆不含內含物的電氣石在激光撞擊其表面後被破裂 （樣品中心的白點是由另一個能量較小的激光脈衝引起的）。

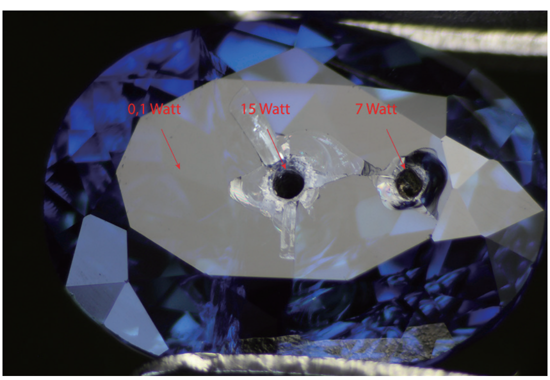

Fig. 9 Experiment using three different laser energies (0.1, 7 and 15 Watt). *Photo: K. Schollenbruch, GGL.*
使用三種不同的激光脈衝（0.1、7 和 15 瓦）進行實驗。

To assess the relationship between laser energy and resulting damage, we used a synthetic sapphire which was hit by a single laser shot on three positions, each with a different laser energy (0.1 W, 15 W, 7 W). As expected, the strongest impact and greatest laser damage occurred when the highest laser power was applied (Fig. 9).
The laser shot at 0.1 W energy did not leave any traces on the stone. The 15 W shot created a hole that went right through the synthetic sapphire. Simultaneously, numerous and extensive fractures were created around the laser hole but only very little glassy substance was found. The laser shot at 7 W created a deep cone-shaped cavity (about half the depth of the stone) with some cracking around the drill hole, but notably also considerable brownish glassy residue (from the local melting of the synthetic sapphire) in and around the laser hole.

Conclusion

As mentioned before, the starting point for this experimental study was that the authors had recently came across a number of cases in which the sort of laser damage discussed above were observed on stones submitted to the Swiss Gemmological Institute SSEF and Gubelin Gem Lab by clients for gem testing. Some of this laser damage was even visible to the naked eye. All were found either on the pavilion or at the girdle (Fig. 10 a-c) in next page.

The laser damage encountered in clients' stones is often close to the girdle, in positions where there might previously have been a prong setting . When doing repair work on these prongs, the laser probably hit the stone causing the damage, either on the side of the repair area, opposite the repair area, or in more than one random spot. So, despite claims that laser repair does not cause damage to gemstones, the jeweller must make sure not to hit the stone accidentally. In addition, the power of the laser beam also has a great influence on the damage caused.

Although, to date, we have only noticed such laser damage on corundum sent in by clients, these experiments have shown that all sorts of gems are subject to this sort of damage. Surprisingly, gems with fewer inclusions are affected more than included gems, indicating that the localised heat produced by the laser is possibly better conducted along fissures and inclusions. Based on our experiments, the extent of the laser damage is also at least partially dependent on the type of gemstone (mineral species) as a result of their different thermal conductivity. Due to the deep cone-shaped areas of damage created by the laser,

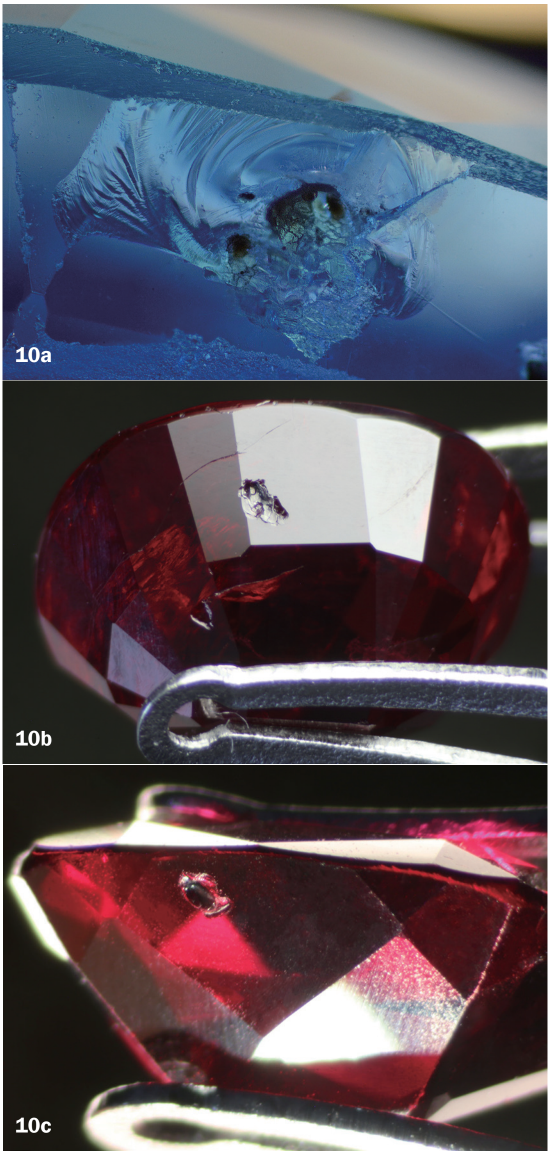

Fig. 10 Three stones of high commercial value showing laser damage very similar to those obtained on our samples using a jewellery repair laser. (10a: sapphire from Kashmir, 10b: ruby from Madagascar, 10c: ruby from Mozambique). *Photos: M.S. Krzemnicki, SSEF and K.Schollenbruch, GGL*
三顆具有高商業價值的寶石顯示的激光損傷與我們使用珠寶修復激光在樣品上獲得的損傷非常相似。（10a：克什米爾藍寶石，10b：馬達加斯加紅寶石，10c：莫桑比克紅寶石）。

re-cutting of such a damaged gemstone may result in a substantial loss of weight. This is especially worrisome in the case of a high-value gemstone, such as the 5 ct Kashmir sapphire presented in Fig. 1.

To summarise, damage caused by a jewellery repair laser can be a real problem for the jeweller. It is, though, a dilemma which could be easily avoided either by not using such laser equipment for jewellery repair, or by having laser repairs carried out only by highly experienced staff.

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