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Laser Engraving Gulf Pearl Shell - Aiding the Reconstruction of the Lyre of Ur

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Abstract The Lyre of Ur was one of two bull's-headed harp instruments that British archaeologist Sir Leonard Woolley recovered from a mass grave during his highly publicised excavations of Ur's Royal Cemetery in the 1920s and 30s in Iraq. Recreated unplayable models of the Lyre are held in Pennsylvania, London and, until recently before it was vandalised, the Baghdad Museum. It is believed that the original Lyre is approximately 4750 years old. An attempt to recreate an authentic playable version is being spearheaded by Mr A Lowings of Stamford. The instrument is to be ornamented by a golden-sheeted bull's head and geometrically inlaid lapis lazuli as well as engraved gulf pearl shell plaques depicting Sumerian images, which are to be placed on the front of the lyre. Authentic cedar wood from Baghdad was used to create the main framework of the lyre. Due to the intricate designs required for the shell plaques an investigation to laser engrave them was undertaken. The main objective when laser engraving the pearl shells (which are chiefly calcium carbonate) was to achieve sufficient depth without compromising image quality so that the plaques could be backfilled with bitumen in order to replicate the originals. Moreover, it was imperative to recreate the images without damage to the surrounding pearl either by scorching or re-depositing removed material. Experiments were carried out to engrave the shells utilising a Synrad CO₂ laser which has galvanometer controlled mirrors to direct the beam which enables it to be scanned in an XY direction across the surface of the target material. An image software package was used in conjunction with the laser so that the images could be manipulated in terms of size and positioning. It was necessary to remove excess material produced between successive laser passes using a soft brush to allow full penetration of the laser beam to the newly created lower surface level. Successful engraving was achieved using multiple laser passes and an identified optimum-processing window.

1. Introduction

The world of art conservation has for some time now embraced the use of laser technology to optimum effect due its versatility, controllability, selectivity and environmental compatibility. [1,2] These unique characteristics have been demonstrated effectively in the treatment of many works of art in particular laser cleaning [3-8].

Traditional conservation techniques have in the past utilised solvent and mechanical removal techniques, which have caused lasting damage [9] hence steps were taken to develop novel laser systems capable of tackling ever demanding conservation challenges as well as preventing damage to the precious artefacts.

This paper discusses the use of laser technology for engraving mother of pearl shell plaques as part of the reconstruction of 4000 year old Sumerian Treasure.

2. Background

Amongst the estimated 170,000 valuable antiquities that filled Iraq's Baghdad Museum prior to its tragic looting in April 2003, some of civilization's oldest musical instruments were proudly exhibited. One such instrument was The Golden Lyre of Ur which was one of more than a dozen Sumerian stringed instruments discovered at the ancient site of Ur in 1929. Headed by British archaeologist, Sir Leonard Woolley, a multi-national expedition excavated the instruments at the "Royal Graves of Ur." These burial sites yielded some of Mesopotamia's most cherished artefacts, providing an astounding wealth of new information about Sumerian culture and the origins of music in civilization. [10,11]

The Golden Lyre was found in the grave of 'Queen' Pu-Abi along with seventy four bodies, presumed to be sacrificial victims, and numerous fine jewellery, stone and metal vessels. One body was found draped over the Lyre, the bones of her hands were placed where the strings would have been.

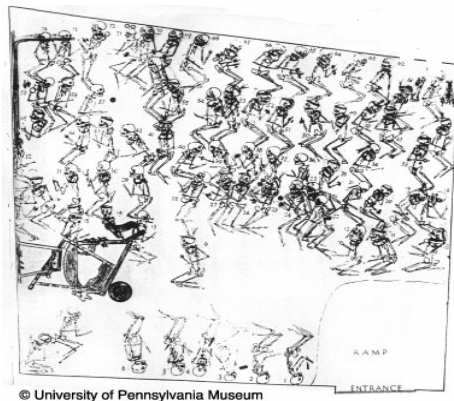


Fig 1: Great Death Pit Sketch, depicted by Sir Leonard Woolley



Fig 2: Excavation site of Golden Lyre of Ur in 1929

The wooden parts of the Lyre had decayed in the soil, but Woolley poured plaster of paris into the depression left by the vanished wood and so preserved the decoration in place. The front panels were made of lapis lazuli, Gulf shell and red limestone originally set in bitumen and helped determine the instrument's shape. The gold mask of the bull decorating the front of the sounding box had been crushed. Strips of waxed cloth were placed over the Gold Lyre to remove it from the ground. The cloth acted like a sheet of glue, holding the instrument's sound box, arms, cross bar and inlay in place. The instrument was then taken from the excavation to be restored. When the waxed cloth dried, sketches and accurate measurements of the Gold Lyre were made. New wooden parts were crafted and the ancient mosaic borders and decorations were transferred from the cloth to the new wooden reconstruction.[12-15]

The lyre remained in the Baghdad museum until it was looted and destroyed, This led to the English harp enthusiast, A Lowings, setting about recreating this piece of history.

3. Method

Original Sumerian images, which were depicted on the Lyre, were obtained in a bitmap format courtesy of Loughborough University. The images were transferred onto a graphics drawing canvas, which is part of a laser marking software package.

The software was used in conjunction with a Synrad CO₂ laser marker. The laser delivers a near parallel beam of 10.6 microns wavelength at a maximum power in the order of 25W with a beam diameter of approximately 200 microns. The beam is delivered to the workpiece using a scanning head system, which contains two galvanometer driven orthogonal mirrors. These mirrors direct the beam through a special focusing optic, which converts the angular deviation of the beam into a linear displacement of the beam within a plane-focussing field. The controllable laser parameters are: laser power (10-100%), the traverse speed (mm/s) and the resolution. In effect the resolution, given in DPI (dots per inch) determines the overlap of adjacent passes. Systematic changing of each individual laser parameter was undertaken in order to establish a processing window which not only clearly ablated surrounding shell to create each engraving but also to prevent re-depositing of ablated material and scorching of the underlying shell. Light brushing across the surface of the shell was undertaken between each successive laser pass to remove ablated material and prevent the laser interacting with it. The ablated material was collected and observed using Optical Microscopy. Each shell plaque engraved was 25.80cm². Plaque thickness was 2.8mm and a viable etch depth required in order for bitumen backfill to be successfully applied was 1.2mm.

4. Results and Discussion

Successful engraving of the shell was achieved operating the laser system at full power with a scan velocity of 500 mm/s and a DPI of 600. The shell was positioned at the focus of the laser approximately 242mm below the laser scanning head. Six consecutive passes of the laser were used and removal of ablated debris was necessary between successive passes by lightly brushing the surface.

The etch depth of the shell for each laser pass and removal rates were calculated and are shown in figures 3 and 4. One complete laser pass took approximately 185 seconds.

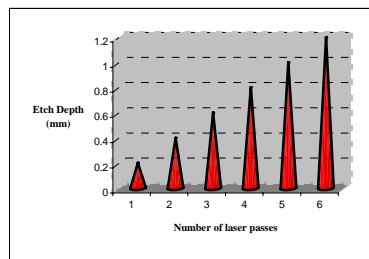


Fig 3: Etch depth achieved with each laser pass

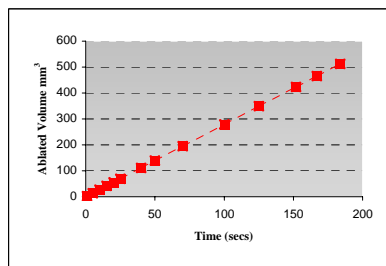


Fig 4: Ablation rate of shell with time

Figure 3 shows that in order to achieve an etch depth of 1.2mm required, six passes of the laser were necessary. It was assumed that the same volume of material was ablated with each laser pass and on further investigations this was proven, as accurate measurements of etch depth were taken between each pass using vernier callipers on test pieces of shell.

Figure 4 shows the shell ablation rate with time. It is seen to steadily increase with time. The graph covers the time period of the first laser pass. From known dimensions of the shell plaques, required etch depth and time taken to complete one pass, a simple calculation was made to determine ablation rate. This was found to be 2.8mm³/sec.



Fig 5: Laser engraved shell plaques before backfill



Fig 6: Laser engraved shell plaques with bitumen backfill

Figures 5 and 6 both show the finished laser engraved shell plaques. Figure 5 is prior to the backfilling of bitumen and figure 6 is with bitumen backfill added in

order to replicate the originals. Figure 7 shows the shell inserts on the replica Lyre. Figure 8 shows the completed replica Lyre.



Fig 7:The replica mother of pearl shell inserts in situ



Fig 8: The replica Lyre with its gold bullhead and other decorative features

A heat conduction analysis is presented to characterize the ablation of the shell by the laser radiation.

A one –dimensional thermal model is considered;

Let us suppose that;

1. A uniform heat flux (I_0) impinges on a planar semi-infinite surface during time t .
2. The heat is conducted inward into the material so that the temperature varies with depth (z).
3. The thermal properties of the material are constant and do not vary with temperature.
4. No overlapping takes place in the scanning, hence a pulse length ~ 1 ms was calculated using spot size, distance covered and time to complete scan.

For a stationary system and heat flow in one dimension, the temperature is given by;

$$\nabla^2 T(z,t) - \frac{1}{k} \frac{\partial T(z,t)}{\partial t} = - \frac{A(z,t)}{K} \quad (1)$$

$T(z,t)$ = temperature at distance z after time t

$A(z,t)$ = heat produced per unit volume and per unit time as a function of position and time

K = thermal conductivity

k = thermal diffusivity

If a constant flux I_0 is absorbed at the surface ($z=0$) and there is no phase change in the material, the solution of the above equation is:

$$T(z,t) = \frac{2\alpha I_0}{K} \sqrt{kt} \operatorname{ierfc}\left(\frac{z}{2\sqrt{kt}}\right) \quad (2)$$

Where ierfc is the integral of the complimentary error function

At the surface ($z=0$):

$$T(0,t) = \frac{2\alpha I_0}{K} \sqrt{\frac{kt}{\pi}} \quad (3)$$

Where α = Absorptance (= 1 - Reflectance)

I_0 = Incident flux

In order to calculate temperatures on the surface of the shell with consecutive laser passes it is assumed that due to surface roughening effects and hence multiple reflections the absorptivity of the material will increase. All constants used are for that of typical minerals. Predicted temperature rises, calculated using equation (2) based on absorptivity increases between 0 and 85% were between 423°C and 650°C, which is well below the melting temperature of CaCO_3 , which is 825°C. Hence it becomes apparent that the mechanism in which the material is removed involves little or no vaporisation, which was evident from the need to constantly remove solid ablated material from the shell surface between each successive laser pass. Figures 9 and 10 show optical micrographs of the ablated material. It is evident from the image that no melting has taken place due to the irregularity in shape of the particulate material. For organics and geological materials such as mother of pearl the important mechanism is due to photomechanical fracture (laser induced stress) which induces stresses in the material in excess of the material strength causing fracturing and rupturing of the surface. Due to the pulse length being of the order of milliseconds, this 'particle ejection' mechanism is consistent with other work in this field, which suggests that mechanisms at shorter pulse lengths involve melting, vaporisation, ionisation and shock waves.

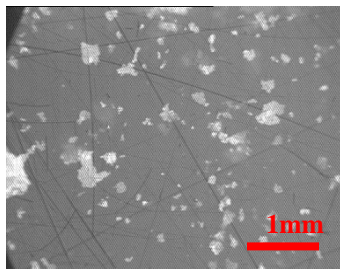


Fig 9: Optical Micrograph of ablated material magnification x10

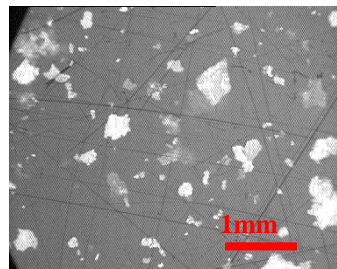


Fig 10: Optical Micrograph of ablated material magnification x10

6. Conclusion

The use of a scanning low powered CO₂ laser is an extremely useful tool for the engraving of difficult materials such as mother of pearl. Depending on chosen parameters it is possible to remove small volumes of material and hence allow the user greater scope to engrave intricate and fine designs by reducing the threat of scorching or destroying the workpiece. The longer pulse lengths suggest that laser-induced stresses on the surface are responsible for ejection of the shell in particle form, which was consistent with microscopic observations of the material ablated.

Overall it can be stated that the laser technology used aided the reconstruction of the Lyre of Ur in a positive way.

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