Abstract

Laser marking of metals and plastics is one of the most widespread of all laser materials processing techniques used throughout the industrial sectors. One remaining challenge is the creation of scanner readable marks on highly reflective materials such as aluminium without the aid of a surface coating. In previous work the authors have presented a novel technique employing a high average power diode pumped solid-state Q-switched laser to locally change the surface roughness, creating high contrast regions between highly scattering laser roughened marks and the unmarked reflective substrate. In this paper the effect of surface modification is quantified and analysed for aluminium, and the techniques are transferred and adapted to other widespread industrial materials such as stainless and galvanized steel. In this way the authors demonstrate the applicability of this laser technique for a range of reflective metals. Applications such as traceability and security are discussed for high volume industrial sectors such as automotive manufacture.

Introduction

The laser marking of different materials to rapidly create indelible marks is probably the most widespread of all laser materials processing applications. It is also one of the most well established laser processes and has been employed extensively in industry. It can offer significant benefits over conventional marking techniques such as stamping and printing, which in many instances can outweigh the greater capital cost of a laser marking system. The benefits of laser marking include excellent contrast, indelibility, cosmetically attractive marks, very high speed, software control, no tooling and versatility. Industrial lasers of all types are used for marking, and virtually all varieties of material can be marked: metals, plastics, natural materials (e.g. wood, paper and even foodstuffs), ceramics and semiconductors. [1]

Figure 1 above illustrates a typical layout for a laser marking system. A laser beam is collimated and directed into an industrial scanner unit. Within this unit are two high-speed galvanometric scanning mirrors, which deflect the beam into a focussing lens. In modern laser scanning systems, the lens employed is typically a flat field lens to ensure that the laser focus plane is consistent across the working area. The laser beam can be moved rapidly relative to the workpiece, and by controlling laser and scanner parameters a high quality mark can be created. Current leading edge laser scanners can offer accuracy and repeatability of <5 µm with marking velocities of up to 10 m/s, and can mark up to 1000 characters per second for certain applications [3].

Mechanisms for marking can broadly be divided into two categories: marking by material removal and marking by surface modification. In the first instance the laser creates a visible mark either by melting or vaporisation. In the second instance the laser radiation affects the material composition to create a high contrast mark without material removal. It may locally melt the material, causing it to oxidise or chemically alter to form a visible mark by photochemical decomposition.
Barcode Scanners

In order to engrave a scanner readable barcode it is first necessary to understand how a typical industrial barcode scanner functions. This type of barcode reader is illustrated in Figure 2 below.

![Figure 2: A schematic of barcode scanner operation](image)

The scanner contains a laser diode, which is swept across the barcode typically by means of a rotating optic. Light scattered from the barcode is received by the photo-diode and the information is interpreted by the decoding electronics. The barcode is readable because the black and white sections of the barcode reflect the incident light differently, and the scanner can therefore determine the mark to space ratios of the barcode pattern. Factors that make a bar code readable are an adequate contrast between the light and dark bars and having all bar and space dimensions within the tolerances for that type of barcode.

Laser Engraved Aluminium Barcodes

One method of laser engraving a barcode is to modify the surface roughness in order to change the reflectivity. The key to developing this process is to identify laser-engraving parameters that suitably change the surface reflectivity.

The change in surface reflectivity will be examined experimentally using the test setup shown in Figure 3. A visible red laser diode is directed on to the laser engraved sample. An optical chopper is employed to create a regular signal variation. A lens is employed to re-image the laser beam at the substrate on to the optical detector, in this case a fast rise-time photodiode. The angle of incidence of the laser engraved sample can be varied - this is a key parameter. By comparing the signal from the unprocessed, uncoated Aluminium with that of the engraved regions, it is possible to examine the contrast achievable.

![Figure 3: Experimental set-up for quantitative tests](image)

Experimental Results

A laser engraved sample is created with a grid of 2x2 mm squares. Each square is produced with a single pass and the time to produce each square is between 100 to 400 milliseconds depending on overlap. The typical depth of each square is between 100 to 200µm. Two parameters are varied within this grid, laser pulse repetition rate (from 20 to 50kHz) and pulse overlap (from 75 to 95%). The sample is shown in Figure 4. This figure gives an indication of how surface roughness varies for each square in the matrix. A broad trend emerges of greater surface roughness being achieved at high overlap and rep rate.

![Figure 4: Laser engraved Aluminium sample plate](image)
Reflectivity tests were performed on aluminium engraving with a sample inclination of 15° and 30°. The results of these tests are shown in figures 5 and 6. These results show that the difference in measured signal is much greater for 30° than for 15°. Whilst the effect is broadly consistent for all repetition rates, 20kHz clearly results in the greatest scatter, particularly at low overlap. By controlling the angle of incidence and laser parameters it is possible to create marks on the Aluminium that have a significant optical contrast (>3:1 at 30° and 20kHz). It suggests that this technique may allow the creation of scanner readable barcodes on uncoated Aluminium [4].

The conventional logic for a laser marked barcode is that the laser-marked region absorbs more light, reading as ‘black’ whilst the untreated region reflects/scatters more light reading as ‘white’. This is why conventional laser marked barcodes on Aluminium are not scanner readable because there is insufficient contrast between the laser marked and unmarked regions.

The results we see for laser engraved Aluminium versus the unprocessed material at 30° are such that this relationship is reversed. The unprocessed Al scatters much less light back to the detector than the laser engraved regions. Therefore the laser engraved regions read ‘white’ whilst the untreated Al reads as ‘black’.

### Alternative Materials

Aluminium is a material of increasing importance in the automotive industry, however the majority of automotive components are still manufactured from steel. Therefore whilst this process is interesting for industrial users of Al, it would be more compelling if the same technique could be applied to more conventional metals as well. If this were the case then laser marking of barcodes with high power Q-switch DPSS lasers could become a versatile and comprehensive identification solution for automotive manufacturers worldwide. Therefore two other key materials are investigated galvanized steel and stainless steel.

### Galvanized Steel

Similar experimental tests were applied to galvanized steel as was applied to Aluminium. A grid of laser engraved 2x2mm test squares was created which is shown in figure 7. Each square within the grid was engraved using a single pass with variation in laser pulse repetition rate and pulse overlap. This grid can then be tested using the same analytical set-up previously described.

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**Figure 5**: Results of reflected scatter trials with sample inclined at 30°.

**Figure 6**: Results of reflected scatter trials with sample inclined at 15°.
It can be seen that there is more evidence of visible oxidation on this sample, which may affect the optical characteristics of the engraved regions. The galvanized steel also appears to be less reflective than the Al sample in previous study. The figures below show scatter versus angle of incidence.

Figures 8, 9 and 10 show the difference in scatter at 5°, 15° and 30° respectively. It is clear in all three cases that the unprocessed galvanised steel scatters more light back to the detector than the laser engraved regions. This is exactly the reverse of the Aluminium results previously described in this paper. The difference in signal between unprocessed and laser engraved material is greatest at low angle of incidence. For 5 degrees angle of incidence the contrast ratio is around 10:1, for 15 degrees it is around 2:1 and for 30 degrees it is <2:1.

This is a complete reversal from the premise of the Aluminium optimised engraving, and would suggest that optimal barcoding performance for galvanized steel would result where the barcode is read at a low incident angle and where the ‘black’ regions correspond to the laser engraved portions and the ‘white’ regions to the unprocessed metal. Therefore for this material it appears that conventional barcode marking logic is appropriate.

**Stainless Steel**

Exactly the same experimental test procedure was applied to stainless steel as to galvanized steel. A grid of laser engraved 2x2mm test squares was created, each using a single pass with variation in laser pulse repetition rate and pulse overlap. This grid can then be tested using the same analytical set-up described in the previous sections.
Figure 11 shows the test matrix for stainless steel. At high overlap there is evidence of significant uncontrolled melting, heat damage, dross and oxidation. This figure demonstrates that regardless of the optical properties of the resulting engraved areas that some of these settings would have to be adjusted in practice to avoid damaging the component to be barcoded and also to ensure that the unprocessed areas are not contaminated. Contamination may obscure and prevent the reading of the high contrast lines required by industrial barcode scanners.

Figures 12, 13 and 14 show the difference in scatter at 5°, 15° and 30° respectively. It is clear in all three cases that the unprocessed stainless steel scatters more light back to the detector than the laser engraved regions. The trends that emerge are all but identical to those for galvanized steel. Optimal contrast is achieved at low angle of incidence and the backscatter from the unprocessed metal is much greater than that for the laser engraved regions. Therefore the best barcode method for stainless steel is the same as for galvanized steel.

Comparison of barcodes of all three metals

Employing optimised parameter sets for each distinct metal it is found that it is possible to create scanner readable barcodes in all cases; thus proving the validity of the analysis above. No post processing is required and an excellent read ratio is achieved using a CVL.490 SICK scanner [5]. The key difference is that for Aluminium a ‘negative image’ barcode is created which is best read at an angle of around 30°, whereas for both galvanized and stainless steel a conventional barcode image is created which is best read at an angle of around 5°. Therefore it is demonstrated that high average Q-switched DPSS lasers can be employed in an industrial environment to make scanner readable, high quality, indelible marks upon three of the most widely used metals in industry. This represents a highly flexible solution, as the laser parameters required for each different material can be controlled by software, and so a single laser processing station could barcode a wide variety of components made of dissimilar metals.
Figure 15: Barcode on galvanised steel

Figure 16: Barcode on stainless steel

Figure 17: Barcode on aluminium

Conclusions

In this paper the authors have investigated the use of high average power Q-switched diode pumped solid-state lasers at the fundamental IR wavelength for engraving metals. These laser and scanner parameters have been optimised for engraving scanner readable barcodes by changing the surface roughness.

Aluminium, galvanised steel and stainless steel were investigated and it was found in all 3 cases that there are laser-scanner parameters that allow good contrast to be achieved. Barcodes were then engraved and these were successfully read with an industrial barcode reader.

For aluminium it was found that the sample needs to be inclined in order to achieve a high contrast. Optimal settings are found to be a 30° read-angle and the laser engraving at 20kHz with a 75% pulse overlap.

For galvanized steel and stainless steel the results show that the contrast is greatest at a low angle of incidence. Therefore high quality scanner readable barcodes can be made on these materials using the same type of laser, but they are made using conventional barcoding logic i.e. the laser engraved region reads ‘black’ and the unprocessed region reads ‘white’. Optimal settings are found to be a 5° read-angle and the laser engraving at 30kHz with a 75% pulse overlap.

Samples are created for all three materials and tested with an industrial scanner manufactured by SICK GmbH. All are found to read easily and with a high degree of tolerance, corroborating this analysis. No post processing was required for any of the samples.

Consequently the authors conclude that it is possible to rapidly create high quality, indelible, scanner readable barcodes on three very commonly used materials: Aluminium, Galvanised Steel and Stainless Steel using the same type of laser. We believe this technique may have many applications, particularly in the automotive industry, for traceability and security of components, sub-assemblies and Body-in-White.

References


3. Scanlab website, July 2006

Figures 15, 16 and 17 show fully scanner readable barcodes created at optimised settings using a Q-switched high average power DPSSL. No post processing was employed for any of these samples. To show optimal contrast, the two steel images are taken at an angle of incidence close to normal, whilst the Al image is taken at a greater angle.

Further work is proposed by the authors to investigate the use of laser polishing to enhance the reflectivity and consistency of the unprocessed material. Additional commercial drivers are to create barcodes that can be read both before and after painting.

5. SICK website, July 2006.

Meet the Author

Paul Harrison obtained his B.Eng in Electrical Engineering and Electronics from Brunel University in 1992. Since 2001 he has been working for Powerlase Ltd, an innovative UK manufacturer of state-of-the-art DPSSL’s, where he is the Project Manager for the Applications Group. He became a Chartered Electrical Engineer in 2004. He is currently studying for an Engineering Doctorate in Laser Materials Processing at Heriot-Watt University.