Laser deep marking of metals and polymers: potential interest for information coding

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Abstract. Preventing and reducing the impact of counterfeiting activities are among the most important preoccupations for modern companies to preserve and protect the value of their work. Some technologies use LASER marking to code information in 2D, directly on material surface. In this work, deep marking of several materials is investigated. The purpose is to use the depth of a marked surface (for different materials: metals and dielectrics) as a third data storage axis. The idea is to convert a performed depth in a grey level in the reading procedure. This marking depth can be then used for coding. Best results are obtained with polymers when transmission lightening is used for reading.

1. Introduction
Laser marking has known a broadening interest in the past decade because of its wide use in industrial applications [1]. Direct laser engraving on a surface is a very flexible method that allows permanent marking of information via for instance 2D data matrix codes [2]. A wide range of applications can be addressed, but industrial processes have to pay attention to the influence of the material on which the marking is done. In metals for instance, laser marking may modify the characteristics of the treated surfaces and thus the resistance to corrosion. This property can be of crucial interest in the field of biomaterials to allow the identification of surgical tools as well as prostheses. In this field, marking with ultra fast laser pulses can be interesting despite the still high cost of femtosecond technology. Femtosecond laser marking provides an electrochemical ennoblement. Moreover, the chemical composition is not affected so that the passive character of both stainless steels is maintained, even improved if we consider the susceptibility to localized corrosion [3, 4].

Due to the drastic increase of product imitation, there is a high interest in new protection methods providing new security features. Invisible laser markings within or below paint layers have been proposed using IR reflection technique [5]. For dielectrics, ultra fast technology allows to develop 3D marking since ultra fast laser pulses can modify the index of refraction in the bulk of transparent materials [6]. Femtosecond photo inscription can be a candidate for optical data storage. More generally, laser marking can be used not only for identification (logo marking, ..) but also for traceability, if data can be stored during the marking process. All methods are indeed limited by the ability of a reliable reading procedure. In the case of laser marking, the visual appearance of the results depends on several parameters: the pulse number, the laser
fluence and the marking precision. Marking and reading methods have to be investigated at the same time to define really efficient new procedure of marking, compatible with an industrial use.

In this work, deep marking of several materials is investigated. The purpose is to use the depth of a marked surface as a third data storage axis. The idea is to convert a performed depth in a gray level in the reading procedure. The exact relation between the obtained depth by laser ablation and the read gray level has to be carefully established. The marking depth can be then used as a mean for coding. Ultra fast pulses are used since it has been previously established that a precise ablation can be performed using these pulses, with a depth precision of some hundred of nanometers [7]. Ultra short pulses are also known to ablate every kind of materials and are thus well adapted for a first work on both metals and dielectrics. Transmission and reflection methods are presented and analysed in terms of logarithmic methods have been developed previously [8].

2. Experimental procedure for deep marking

2.1. Experimental set-up

The laser system was a Ti:Sa laser chain which delivers 150 fs pulses at a repetition rate of 5 kHz. The used laser fluences are in the range from 0.814 J/cm² for PVDF polymer to 2.54 J/cm² for stainless steel. The moving laser beam was focused with a lens of 14 cm as focal length and the samples are placed at the image point of an aperture fixed in the set up. The beam diameter on the surface of the sample was fixed at 50 µm. The overlapping of two marking lines was fixed to 10 µm. The basic step of deep marking (corresponding to a precise depth for each materials) correspond to four laser passes (one horizontal, one vertical and two crossed diagonal pass). This ensures a relatively smooth surface.

![Experimental set-up](a) and beam overlapping (b).

To test the reading method, square features (0.5 mm × 0.5 mm) are performed at several depths, i.e. repeating several times the basic laser processing defined above. Six levels of depth are then chosen and a test matrix is defined (Fig. 2), to be marked on several materials like polymers and metals.

2.2. Reading procedure

Two types of reading procedures have been considered: image acquisition by transmission or reflection. In the former case, a back light device is used and in the second case a LED device is used. The images are stored using a commercial CCD sensor (1/4 inch, 0.33 Megapixel (VGA), color CCD). Some examples of stored images are reported in Fig. 3.

3. Deep marking and grey levels

The physical processes allowing the marking through material modification are not the scope of this preliminary work. The correlation with the images shown above, taken in grey levels by
Figure 2. Test matrix with six levels of depth.

Figure 3. Deep marking on metal (stainless steel) with lightening by reflexion (a), on polymer lightening by transmission (b), on polymer with lightening by reflexion (c).

the imaging device, and the exact depth is made thanks to a direct measure of the depth with a optical means (Fig. 4). The polymer used in this study is PVDF (Polyvinylidene Difluoride).

The obtained depth for the six levels defined above are reported in the table 1 for PVDF.

Table 1. Obtained depth for each level of deep marking in PVDF.

| Level | Measured depth (µm) |
|-------|---------------------|
| 1     | 0                   |
| 2     | 50                  |
| 3     | 96                  |
| 4     | 156                 |
| 5     | 190                 |
| 6     | 231                 |
Figure 4. 3D representation of marked samples with optical means. These measurements allow a precise depth determination of each square in the matrix and the correlation to the grey level of the stored image with the imaging device.

3.1. Analysis of stored features by transmission lightening
The correlation between measured depth and grey level obtained by the imaging procedure is made for each square of the matrix. The grey level is determined by calculating the average of each square’s pixel of the matrix. For each cell, the obtained grey level is then associated to one of the six depth levels. A dispersion of the results can be seen and is reported in Fig. 5 where an average grey level of each depth level is shown with error bars. Nevertheless a logarithmic analysis of the correlation can be done [8] and the overlapping of errors bars is not so high to prevent any clear analysis of the grey levels in the stored image in terms of marked depth. As shown previously [8], the attenuation of an image intensity due to light absorption has a logarithmic evolution. So in the present case, the different square depth lead to different light absorption in transmission, and then different grey level.

Figure 5. Correlation between grey levels and depth. Case of PVDF, lightening by transmission.

3.2. Analysis of stored features by reflection lightening
The above presented results are obtained with back light. If reflected light is used in the imaging procedure, the results can be quite different. Of course a method by reflection has to be used for
metals for which transmitted light cannot be used. The same analysis method is performed to obtain grey levels to be associated with measured depth on the samples. Fig. 6 presents results for PVDF.

![Figure 6. Correlation between grey levels and depth. Case of PVDF, lightening by reflection.](image)

As evidenced on Fig. 6, the overlapping of grey values is too high for each depth level to reach a satisfactory precision. Depth analysis using grey levels is not reliable for reading written information. It is the same results and even worse in the case of metals, as shown in the case of steel in Fig. 7. In this case no correlation between grey level and depth can be evidenced. It is difficult to say if these bad results are due to a bad surface quality for reflecting light or if the image analyse is not adapted.

![Figure 7. Correlation between Gray levels and depth. Case of steel, lightening by reflection.](image)

4. Conclusion and further works

As a conclusion of the present work, laser deep marking of materials can be a tool for coding, if transmission lightening is used for reading. This primary result excludes non transparent materials such as metals. Transparent polymers seem to be a good choice as basic materials to store information in 3D by laser marking, using a dedicated processing method to obtain deep marking. As laser ablation rates are usually rather low in polymers, the speed of this direct marking method should be competitive, but it has to be demonstrated by further works on real industrial codes to be marked. Ultra short pulses are known to be suited to precise polymer ablation. Other non IR laser beam, to prevent thermal effects on polymers, can be also used.
but no experiment is done in the present work. To complete the present study other transparent materials such as glasses should be considered. Nevertheless, in this case ablation rates are higher than in polymers. Then, as mentioned above, the real physical mechanism allowing the grey level observation has to be clearly understood. The 3D measurement of the samples made in this work has also shown the roughness of the performed squared shapes. This roughness should have an influence on light transmission. Indeed surface structuring is also due to the processing method (several passes of the beam in four directions). The processing steps can be simulated for each square of the test matrix and the obtained roughness is computer converted in grey level and then applied to test matrix depicted in Fig. 2. Simulated matrix is compared to the observed matrix of Fig. 4 and presented in Fig. 10. As a final point, laser deep marking can be a candidate for 3D coding but only on some transparent materials by using back light for reading. Nevertheless a control of surface processing is requested and has to linked to the light absorption in the sample.

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