CHAPTER 5

DISCUSSIONS AND CONCLUSION

5.1 DISCUSSIONS

Investigations of the marking characteristics is carried out with the aim of gaining a better understanding of the marking process as well as identifying the process parameters involved. These parameters are useful for the operation of a film marking system. This study compares the marking quality of two lasers, a specially constructed pulsed Copper Vapour Laser (CVL) and a commercial continuous-wave Argon Ion laser, to investigate the suitability of each of the laser source for film marking purposes. As the motion picture industry currently uses two types of film base, this study also compares the laser marking quality on the Polyester and Triacetate substrate bases.

Film marking results are subjected to both qualitative and quantitative analysis. For quantitative analysis purpose, a digital image processing system coupled with a microscope is employed to investigate the relation of marking widths to the various process-dependent parameters.

For both the laser systems, it is a prerequisite to ensure those laser emission parameters (power, pulse duration, divergence, beam profile, beam pointing and power

stability) and lens selection is suitable. Section 3 incorporates these considerations in construction of the marking system. Beam divergence affects the ability of the beam to be focused into a small spot size. Beam profile affects the transverse uniformity of the laser marked line. Most lasers, including the Argon Ion laser used in this study, emit with a Gaussian distribution profile. The Gaussian profile produces a similarly shaped line profile with a clean centre but with a lot of leftover residues on the edges. These residues must be removed by other means if a clean uniform line is preferred. A flat top profile is preferred over a Gaussian profile to ensure complete emulsion vaporisation without leaving residue on the edge. Achromatic lens with large f-numbers is selected to ensure minimal aberration.

The sealed-tube CVL system has been successfully implemented. The CVL can be operated from 5 to 15 kHz. Using the plane-plane optical resonator, the CVL can produce up to 8 W of output power. Etching carried out using the plane-plane resonator cavity produced rather large marking width (more than 400 microns) due to large beam divergence. In order to reduce focal spot size, an off-axis unstable resonator is employed, which produced a beam with improved divergence. The CVL with unstable resonator produces up to 3 W of output power.

In the course of this study, it is found that CVL is not suitable for marking on film due to its pulsed nature. The unstable resonator employed produces a non-Gaussian beam with very high peak intensity in the centre of the beam with rapidly reducing intensity at the edges of the beam. The edge of the beam consists of significant Amplified Spontaneous Emission (ASE) with large divergence. It is only during the latter half of the pulse that the

beam quality is greatly improved. The ASE causes the edge of the marked line to be large. Temporal instability, a common problem in CVL system, causes the marked line to be irregular and varying in width. Section 4 elaborates on how the photothermal ablation induced by the CVL pulses result in non-selective etching, contrary to the requirement for film marking. The high peak power in the centre of the beam can ablate even the normally transparent substrate. The desired Clear Area formed by CVL often appears yellowish, possibly due to interaction of the ablated by-product with air.

When compared with CVL, the Argon Ion laser provides very good markings with consistent lines. The Clear Area is transparent with the emulsion cleanly removed and the underlying substrates unaffected (Selective etching). The line edges appear black due to the thermally decomposed residual emulsion but not removed by vaporisation. This helps to provide contrast especially in films with bright scenes. These characteristics make laser marking attractive for the film marking industry.

Comparison between laser markings on Polyester and Triacetate substrates show that marking quality is generally better on Triacetate substrates. This is because it is possible to use higher laser fluence to remove more emulsion resulting in cleaner lines.

A quantitative diagnosis method using digital image processing techniques has been developed to overcome the difficulties in measuring etching depth (emulsion is only 8 microns thick) normally reported in published work. The relations between etching width with other parameters were studied rather than etching depth since the etching depth is not a measure of etching quality. The image processing technique uses the microscope to magnify

the images so that measurement accuracy up to 10 microns can be achieved.

Quantitative analysis has been applied to determine the process dependent parameters. It is found that the marking quality is dependent primarily on scanning speed, laser power and the emulsion's absorption coefficient. During the course of the investigations, it is found that for a typical film with colourful scenes, absorption of light varies over a wide range dependent on the colour and brightness (amount of transmission) of a particular scene. Provided that the absorption coefficient does not change by more than 50%, usually a suitable combination of laser power and scanning speed can be found to etch the film with satisfactory line quality. Furthermore, different batches of film require different scanning speeds for proper marking, even if the laser power is maintained. Since emulsion absorption should not change (if the colour and projection quality of the film is to be maintained), the difference in line quality and laser fluence used suggests that the quality of emulsion adhesion to the substrate may be a major factor.

Film substrate	Polyester	Triacetate
Optimum scanning velocity	73 $mm.s^{-1}$ at 1.5W. Subsequently increasing at 24 $mm.s^{-1}.W^{-1}$	68 $mm.s^{-1}$ at 1.5W. Subsequently increasing at 17 $mm.s^{-1}.W^{-1}$
Optimum Clear Area width	65 μm at 1.5 W. Subsequently increasing at 7 $\mu m.W^{-1}$	65 μm at 1.5 W. Subsequently increasing at 7 $\mu m.W^{-1}$
Optimum HAZ width	145 μm at 1.5 W. Subsequently increasing at 5 $\mu m.W^{-1}$	145 μm at 1.5 W. Subsequently increasing at 5 $\mu m.W^{-1}$

Table 5.1. Optimum process parameters.

In order to determine the dependence of optimum marking with laser power and scanning speed, uniformly black films with more than 99% absorption is selected. The optimum parameters for both types of films are summarised in Table 5.1.

The limiting factors affecting marking rates have also been presented in Section 4.3.4. It is found that emulsion vaporisation occurs only when the incident laser fluence threshold of 4 $J.mm^{-2}$ is exceeded. The upper limit of the marking rate is governed by the scanner speed and substrate damage threshold. Higher laser power can decrease the marking time. However, the marking speed is limited by the available scanner speed, which is about 220 $mm.s^{-1}$. At very high fluence, the substrate may be damaged if it is allowed to absorb too much laser energy.

As mentioned earlier, although the centre of the marked line is clean, there is still a lot of residue attached to the line edges. Polyester film tends to have more leftover residue. More leftover residue may result if the emulsion's adhesion to the substrate is very strong. In this case, marking quality may be improved by cleaning the film with either water or alcohol. Using ultra-sonic cleaning method will improve cleaning efficiency. Another way to improve quality is multiple scanning technique. The image is marked two or more times in succession. In this way, the decomposed emulsion not removed during the first scan is removed by laser irradiation during the subsequent scans. However, this technique has implications for required scanner speed. To maintain the same throughput, the scan rates must be increased in proportion to the number of multiple scans.

5.2 CONCLUSION

A galvanometer-based laser film marking system has been successfully implemented. Good quality film markings can be achieved using non-ablative photothermal vaporisation mechanism. Because of this, argon ion laser is preferred over copper vapour laser for film marking.

It is found that laser beam quality is of utmost importance in determining the final marking quality. The laser source must possess good temporal and spatial stability and low-divergence in order to produce small spot size. Although flat top beam profile is preferred, the Gaussian beam profile produced by argon ion laser can produce good markings with dark edges along the marked line. Heat diffusion to the substrate is minimal as clear, clean emulsion removal is possible without damage to the substrate layer (although the substrate decomposition temperature is lower than that of the emulsion). However, heat diffusion to the emulsion can be significant possibly due to the presence of silver halide salts. Heat diffusion loss in the emulsion layer causes the width of the clear area to be smaller when marked at lower power and lower scanning speed. Etching quality of Triacetate substrates are generally better when compared to that of Polyester due to the higher thermal damage threshold of Triacetate. Marking speed up to 180 $mm.s^{-1}$ have been achieved using 6 W output power.

Although not suitable for film marking, the CVL system has been successfully used to produce micro marking of other materials. The CVL system is able to produce very high quality markings on materials such as aluminium, stainless steel, mild steel, copper, glass

and wood. The CVL can produce less than 10 microns spot size on these materials. It appears that the low divergence ASE portion of the beam is too low in power to create marks on these materials.

Figure 5.1. Sample Film Subtitle Markings.

Laser marking will only be useful if the marking system can etch meaningful characters. This requires the development of a vector-based scanning software incorporating the optimum process parameters discussed earlier. The software to draw single-line vector characters has been implemented. Sample laser film markings with both Roman and Chinese characters are shown in Figure 5.1. The lower portion of the film shows the markings using the conventional hot-stamping method.

5.3 SUGGESTIONS FOR FUTURE WORKS

This study involves investigation of the marking results to determine the process parameters. Although these parameters can be incorporated into the software, it still requires user intervention to evaluate the optimum marking quality and fine-tuning the parameters to compensate for the variations in film emulsions and substrates. Improvements can be made to the system by incorporation an in-process or real-time monitoring and control system. As discussed in Section 4, during the marking process, most of the laser energy is used to vaporise the emulsion. The portion of the laser energy that is not absorbed by the emulsion is transmitted through the substrate. Once the emulsion has been removed, excess laser energy transmitted through the film substrate increases dramatically. This leads to deformation of the substrate if the exposure time is long enough. Therefore, a study can be conducted to correlate the excess laser energy transmitted with the optimum marking width. During the decomposition process, the plume is also observed to be incandescent. The light emission's intensity and temporal behaviour can be examined for relevance in the marking process.

Deeper understanding of the process can be gained by monitoring the temperatures associated with the photo-thermal decomposition process using a fast IR optical thermometer. A thermal modelling of the photo-thermal decomposition process can then be carried out.