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Abstract

The BRITE EURAM BE5541 project developed a prototype excimer laser based machine capable of high quality high speed marking on polymeric materials. The cell is a multipurpose design and has been specifically designed and tested for marking computer equipment. The testing and operation of this prototype provided a base for assessing the technical and economic aspects of using this technology. The testing programme demonstrated that excimer laser based systems can provide a faster, more cost effective and flexible method for marking such types of components than the ink or stamping methods currently used

Introduction

During the last three years extensive trials and testing have been carried out aimed at the development of a prototype excimer laser computer keyboard keycap marking system. The main goals for this prototype was its capability of producing high contrast black alpha numeric marks having a contrast ratio greater than 3. Furthermore this marking should be capable of being carried out at high speed so a complete board is marked in -12 s. This corresponds to a yearly marking throughput of- 1 million boards/year, The main advantage of such a laser processing system is its flexibility. Using conventional printing technology, a significant amount of time is spent in setup and testing the quality of the marked keyboard after the printing stamp has been changed to a new keyboard design. Utilising the flexibility of the laser marking process, a changeover between designs can be completed in a few seconds, with the ability to guarantee the contrast of the marked characters being identical to the previous marked boards.

The system developed (called *marking cell*) consists of the following parts: the *XeF* optimised excimer laser source, the optical chain, the mechanical units and the on-line sensor. Before the marking cell could be finalised, an intense work has been carried out to optimise the plastic compounds in order to achieve highest mark contrast and fulfil the production requirements.

Technical description

First tests.

It is well known that the interaction of *UV photons* and plastic materials produces interesting results. One of these is a change of colour which, under particular conditions, can be of extremely high contrast. The mechanism for the colour change is believed to be the photoreduction of the TiO_2. This compound is normally present inside the plastic matrix because gives it a white and non transparent colour and stability to the colour itself. High power radiation from excimer laser can induce photochemical changes in white coloured titanium dioxide, removing some oxygen:

$$TiO_2 \rightarrow TiO_{2-n} \qquad 0 < n < 0.5$$

The resulting non-stoichiometric material poorly reflects visible light and so the marked area turns to a black colour. The plastic materials usually have a high absorption coefficient in the range of wavelengths shorter than the visible field; in fact the absorption- coefficient of polymers in *UV* range is about 10^3 10^5 cm^{-1}, with the absorption of the incident radiation in the polymer, given by the following law:

$$I(x) = (1 - R) \times I_0 * e^{-\beta x}$$

where

- $I(x)$ is the fluence at the depth x
- x is the depth
- I_0 is the fluence on the material surface
- R is the surface reflectivity at the operating wavelength
- β is the absorption coefficient which can be considered as a sum of the contribution of various components of material

$$\beta = \beta_1 a_1 + \beta_2 a_2 + \square + \beta_n a_n$$

where

β_n are the absorption coefficients of each component
a_n are the percentage of each component into the material.

Initially, marking experiments were performed by RTM and then by Exitech onto some polymers used for office equipment housing. Different Lambda Physik excimer laser sources were used at the wavelengths of351 *nm* (*XeF*), 308 *nm* (*XeCl*) and 248 *nm* (*KrF*).

The preliminary tests performed in RTM showed that marks produced by one laser pulse (pulse duration of30ns)atwavelengthof351 *nm* and fluences in the $0.5 \div 0.8\ J/cm^2$ range were dark and well defined, but contrast and depth of colour change were not sufficient to satisfy standards for computer keyboards. Applying more than one laser pulse per unit area, the contrast decreased and ablation of the material occurred. If the fluence was greater $0.8\ J/cm^2$, then single pulse ablation was observed. At fluences below 0.5 J/cm^2, the surface colour change was not enough and consequently the contrast level was not sufficient. The mark threshold was found to be about 0.2 J/cm^2.

At the laser wavelength of 308 *nm* the contrast appeared to be lower (at the same fluence range) than 351 *nm* and also the penetration depth of the mark was significantly less. These two facts are

undoubtedly a consequence of the different photon absorption of the bulk material and the much less pronounced efficiency of the TiO_2 photoreduction. The use of 248 *nm*, as expected, worsened the results: the colour change was very low and the mark penetrated a very short depth ($<10\ \mu m$) so at 248 *nm* the material was found to be more susceptible to ablative etching rather than TiO_2 photo reductive marking.
In further marking experiments the process was optimised using single and/or double pulse at 351 *nm* (*XeF*). This demonstrated to be the more efficient wavelength.

Plastic compound optimisation.

The role of polymer matrix, pigment loading and different additives on mark properties have been studied. These experiments allowed us to find the desired plastic materials. At the beginnig Olivetti focused its interests on a compound made of *PC* (polycarbonate) and *ABS* (*A*crylonitrile, *B*utadiene, *S*tyrene) and additives, which gave excellent results; this compound was used for the *Notebook* keyboard. Due to its high cost the *PC/ABS* compound was not economical for high production volumes; then, to produce new keyboard layouts (such as the "*supercompatta*"), Olivetti chose another compound optimizing both the pure *ABS* and the *PS (Polystirene)*. The plastic compound parameters which were considered are: different suppliers, percentage of TiO_2, different kind of TiO_2, presence of other components (such us $CaCO_3$, $BaSO_4$, *ZnS*), presence of *UV* and *Temperature Stabilisers*, different type of colouring agents.
Conclusions: the interaction between the plastics and the *UV* radiation can produce the requir high contrast mark. This work led to findinf the right plastic compounds in order to get the desired symbol, in terms of rate of colour change (contrast, mark depth, *UV* and wear resistance and so on) and control of the surface modifications (etching and foaming layer). Different kinds of plastic compound were studied and optimised.
Under some processing conditions, a non acceptable white foaming layer was visually present. Underneath this foaming layer the symbol is visible but it exhibits an insufficient contrast; moreover this foaming layer is not easily removable. Particular importance was given to the possibility of obtaining good marking results with several pulses due to insufficient laser energy per pulse to mark a keycap with a single shot. Since the symbol satisfies Olivetti Specs the process parameters have been defined. Moreover the results got with the *ABS* are better than the ones got with *PS*.
In concision the *ABS* can immediately achieve the needs so the research to optimise the *PS* should proceed.

Excimer laser source.

The best results were achieved using 351 *nm* delivered by a *XeF* excimer laser. The colour change showed to be sensitive to the fluence so that, although excimer lasers generally have a good beam profile in comparison with other laser sources, a higher beam homogeneity is also required. The average power of the laser directly controls the throughput. The planned throughput of 1 million keyboards per year demands for a laser power of several 10*W*. This can be achieved with a repetition rate of more than 30 *Hz*. The following target data have then been defined:

Laser Parameter	*Target*
laser medium	*XeF*
typical stabilised energy	450 *mJ*
max. repetition rate	100 *Hz*
max. average power	45 *W*
typical pulse duration	25 *ns*
pulse energy fluctuation	$s \leq 2\%$
typical beam size (FWHM)	10 x 30 mm^2

Beside these technical project goals related to the requirements of the marking process, additional objectives result from economical considerations, Important performance data of any equipment are the mean time between failure (MTBF), the mean time to repair (MTTR) and the equipment dependent up time. These 3 parameters affect the obtainable throughput directly. Target values for these parameters were not defined in the start phase of this project. But with project progress the interest in laser performance data increased significantly. During the last years the electronics industry has demanded more and more aggressive performance data. Therefore, target data was defined for the laser demonstration unit in late 1994.

MTBF	2500 *h*
MTTR	2 *h*
equipment dependent up time	95 %

It was also agreed that the technical layout of the laser equipment should fulfil industrial demands such as ease of use, controller software, and good component access for maintenance and service. Although these factors can not be measured easily their importance for industrial users is high. Due to the continuos change in production conditions to higher efficiency these factors become even more important.

The most important improvements performed on the optimised *XeF* laser are the following:

A **metal ceramic laser tube** was used instead of the standard laser tube; results: the static *XeF* gas life time improved more than 5 times while the dynamic life time by one order of magnitude.

New electrode system; a relatively flat electrode profile was developed which results in a wide discharge and which avoids parasitic discharges when operated in a high power *XeF* laser. The electrode system with the flat profile gave better results than a standard profile. The average power increased from 45 *W* to 54 *W* at a repetition rate of 100 Hz. The horizontal beam dimension increased by about 20°/0 with the special electrode system. The beam cross section is-now 29.3 *mm* x 9.3 *mm* (FWHM). The pulse energy stability is good. The energy fluctuations at 100 *Hz* can be as low as 1.3’74. for 1 sigma. The test laser was successfully stabilised at a pulse energy of 450 *mJ*, the energy required for the planned marking process. The Figure 1 shows an uninterrupted test run over 2.5 days More than 20 million pulses were accumulated on a single gas fill without any cryogenic gas cleaning. The average power stability was ±0.8% over the whole run.

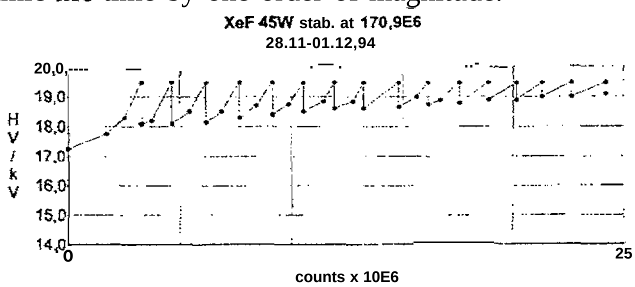


Fig. 1- Long term test

Gas purification: experiments indicated that the output energy of a *XeF* laser may increase with laser gas temperature due to a reduced concentration of XeF_n molecules. The current laser tube design allows a tube temperature of up to 80 “C without major modifications. In test runs a pulse energy increase was demonstrated with rising temperature. A temperature increase from 30°C to 80°C resulted in 25% more pulse energy. Two new methods were developed for gas purification, the first involves running the cryogenic apparatus only during the laser stand-by and the second makes use of a heater located in the gas line which decomposes XeF_n molecules.

New **mechanical and electrical design concepts** have been developed; the laser was separated into two compartments: the upper for the laser tube and the lower for the modules (gas and water module, the high voltage power supply and the control unit) so that easy maintenance and serviceability is guaranteed by large access doors. The new electrical design concept adhered to the following main criteria:

1. Usage of components with proven reliability in order to obtain high MTBF.
2. Continuos laser status recording and data evaluation in order to determine preventive maintenance actions.
3. Easy system architecture for short diagnosis and repair time (low MTTR).
4. High modularity for low MTTR

5. Implementation of many status sensors for easy system diagnosis in order to minimise diagnosis time.

The new controller concept seems to be more complex but it avoids the problem of extremely time consuming failure diagnosis and status recording by high level software and service support.

System choice.

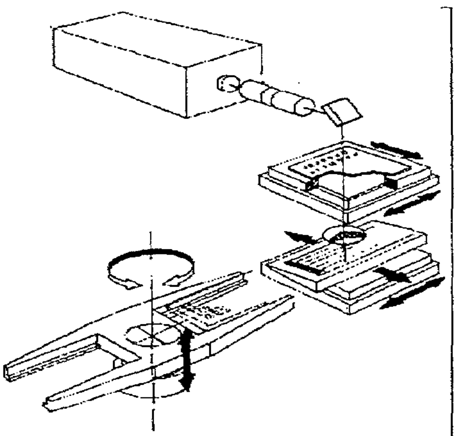


Fig. 2. The solution used.

The study and design activities performed during the first half of our project lead us to take into consideration two possible architectures, with the aim to achieve a better compromise between the industrial requirements (in terms of reliability, simplicity and costs) and the performances that the marking system must have. The basic difference between the two solutions is the mask unit device. In the- first, the mask unit consists of a thin disk made of a dielectric on quartz substrate; this disk has on its circumference all the symbols needed for marking the various keyboard layouts; during the marking process the disk rotates and the laser beam intercepts the symbols which are then imaged onto the keyboard.

The second solution uses a rectangular mask holder, with the same dimensions as the keyboard, this holds the slabs, which are made of a dielectric on quartz substrate; in this case there are two further possibilities: in the first (displayed in the Fig. 2) the beam path is fixed and the mask is moved by means of an *XY* high precision positioning stage to intersect the beam; the motion of the keyboard is synchronised with the mask holder unit by means an appropriate control system. The second possibility uses an appropriate scanning device which directs the beam onto the symbols while the mask is still; this is a very expensive solution because to the need to manufacture extra optical devices (field and imaging lenses) **with** geometrical parameters which are not commercially available; this solution would reach a very high throughput.

In concision, the idea of the rotating mask was abandoned due to the possibilities of the very high speeds of rotation and angular accelerations inducing dangerous stresses in the mask material (quartz) and because it is difficult to realise a reliable system control.

The second solution is valid only in the first possibility, depicted in the Figure 2. It is mechanically simple, the mask does not undergo particularly high accelerations, the stresses are negligible and the laser synchronisation with the mask and keyboard stages can be accomplished by using a simple module Hw/Sw.

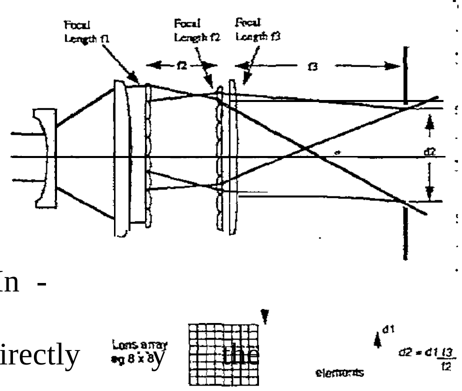
Optical chain

An optical beam delivery system was required with an high optical throughput efficiency at 351 *nm*. This optical system includes beam relay, shaping, homogenisation and imaging optics. All optical components should be antireflection coated for use at the specified wavelength. Two mask designs were considered: the first solution was made as a negative replica of the keyboard. The negative of the mask was then reproduced on the work piece using a 1:1 image projection lens. The dielectric coatings on the mask were designed to have a damage threshold of at least twice the fluence incidence at the workpiece. The second solution deals with a metal coated quartz mask. Metal type and its thickness were studied to tolerate the design fluences. Both the solutions were studied.

AR coatings. To reduce losses all transmissive optical components should be *AR* coated to reduce the Fresnel reflectivity of each surface to < 0.5 %. Because of their ability to reduce reflectivities to 0.1 % per surface while simultaneously having an exceedingly high damage threshold (≥5 J/cm^2 at 351 inn), spun on colloidal silica was chosen as the preferred antireflection coating material.

HR coatings. To reduce losses that arise from turning mirrors in the optical beam train it is extremely important to minimise absorption and scatter that arises from high reflectivity 45° incidence mirrors. For this **reason,** the high and low index dielectric materials from which the multilayer reflective stack is fabricated must be carefully selected. By directly measuring the reflectivity of coating at 45° angle of incidence, different combinations of high and low index materials were tested for producing the highest reflectivity at 351 *nm*.

These tests showed that of the high (Al_2O_3, $GdF2$, ThF_2, HfO_2) and low index SiO_2, Na_3AlF_6, MgF_2) materials tested, the combination of GdF_2 with Na_3AlF_6 gave the highest 45° reflectivity (99.9°/0) and laser damage threshold (> 2 J/cm^2) at 351 *nm*. These materials were then chosen for fabricating all 45° mirrors.



To reduce losses, optical complexity and costs it is often desirable to seek to combine the roles of beam shaping with image relay beam transport together in the same telescope arrangements. In - the marking beam delivery design chosen, use is made of the 30x12.5 mm^2 (2.5: 1 aspect ratio) produced directly the Lambda Physik *XeF* laser to produce the required 2.6: 1 aspect ratio beam on the keyboard using spherical shaping and relay optics **Fig,** 3. Fly's eyes. only. Final magnified imaging (x2. 5) of individual rectangular lenslets of the fly's eye double homogeniser produced the required 13x5 mm^2 beam size on the board which had edges in which the intensity dropped from 90% to10% of the peak intensity in a distance of< *200 μm*).

Beam homogenisation. Of the many methods that can be used to homogenise excimer laser beams such as biprisms, mirror tunnels, kaleidescopes, optical fibers, etc, a double fly's eye lens arrangement *was* chosen (see the Fig. 3) to be the most effective in terms of minimising light loss while simultaneously capable of operating at high laser powers and producing the highest degree of beam homogenisation (≤10% *rms* deviations from the mean intensity) and edge sharpness (90% to 10OA intensity drop in ≤ 200 *μm*). The angles introduced by the fl y's eyes optical components were designed to match the numerical aperture of the imaging lens so the effective coherence factor of the illumination system was close to unity.

The doublet imaging lens designed to project onto the keyboard the character layout featured on the mask has a unit magnification, a 0.05 numerical aperture, a 15 mm image field diameter, a 127 *mm* focal length, and a 500 *mm* total track length. Over its depth of focus of 0.14 *mm* this lens then produces an image on each keycap within its resolution limit of 7 *μm*.

Mask materials.

Because of the I: 1 imaging characteristic of the system architecture adopted, the mask containing the full board keycap features to be marked must be capable of withstanding laser fluences at least as high as those incident on the workpiece. Conventional chrome-on-quartz types of masks as used for photolithography in the semiconductor industry, although readily available are unsuitable for this application since they damage at single pulse 351 *nm* laser fluences of< 100 mJ/cm^2. As part of this project new forms of masks capable of withstanding fluences in excess 1 J/cm^2 needed to be developed. It is known that multilayer dielectric coatings on fused silica substrates as used for fabricating high reflectivity mirrors can withstand fluences of 1 J/cm^2 at 351 *nm*. Providing these coatings can be etched with high resolution patterns to make them highly transmissive in the etched region, then they should likely provide a suitable opaque barrier to transmitted light incident on the mask. An experimental test programme was carried out to determine the optimal etching process for patterning multilayer dielectric coatings.

In parallel the study of aluminium coated quartz masks was carried out; the metal coated mask has a lower cost than dieletric coated one but withstands less to high fluences than dielectric ones.

Using a fenestrated mask holder design that butt couples masks together in the gaps between marks on the keyboard, the difficulty of fabricating large dielectric mask sizes as large as a full keyboard can be alleviated somewhat by fabricating smaller 6" square submasks. Target resolution for pattern etching is< 25 µm over substrate sizes of ≥ 6" square.
This solution is good for aluminium coated masks too but, in this case, sizes as large as the keyboard are easier to fabricate.

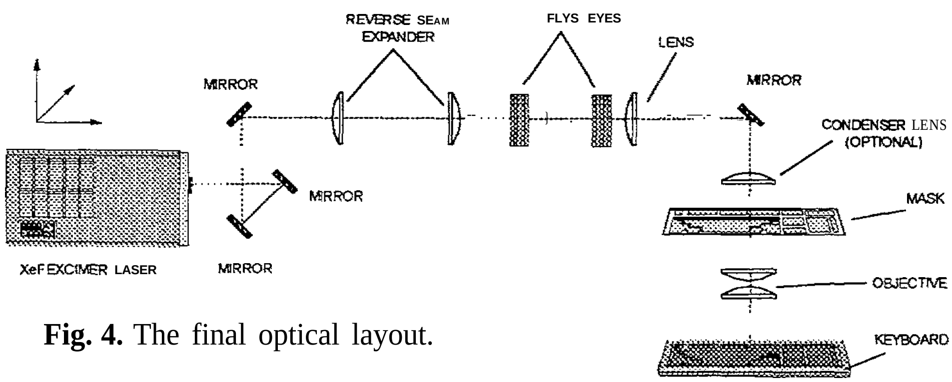


Fig. 4. The final optical layout.

In the Fig. 4 the final complete optical layout is presented. The first 3 mirrors are used to align the laser with the optical chain and rotate the beam by 90°. The reverse beam expander fits the beam dimensions to the fly's eye dimensions. The objective is a doublet which projects the 1:1 image of the mask onto the keyboard. The condenser lens above the mask was not used because the beam dimensions did not exceed the objective aperture.

Mechanical units.

The moving stages are constituted by precision X-Y linear tables, driven by recirculating ball screws, and are brushless electric motor actuated; the mechanical and geometrical parameters are calculated. The main geometrical and mechanical specifications of this positioning system will be:

- total maximum travel: $t_X \times t_Y = \mathbf{450 \times 150mm}$
- position accuracy $\delta = 20\,\mu m/25mm$
- unidirectional repeatability: $\partial = 10\ \mu m$
- straightness and flatness of travel: $\xi = 2.5\,\mu m/25mm$
- overall dimensions:
  - X-axis $l_X \times w_X = 800.5 \times 178\ mm$
  - ***Y-axis*** $l_Y \times w_Y = 496 \times 178\ mm$
- maximum travel speed: $v = 1\ m/s$
- nominal no-load acceleration: $a = 5\ m/s^2$
- maximum load carrying capability:
  - horizontal $F_h = 660\,N$
  - inverted $F_v = 330\,N$
  - side $F_s = 220\,N$
- nominal stage weight (less motor):
  - x-axis $m_X = 10\ kg$
  - *Y*-axis $m_Y = 7.7\ kg$
- stage material: *high strength aluminium alloy*

Axis motion system architecture. The motion system used in the prototype cell is formed by two overlapped symmetrical units; the upper unit is used to move the mask while the lower to move the keyboard. Each unit is composed of two axes which are orthogonal to each other: *X* and *Y* for the lower unit, ***U*** and *V* for the upper unit (see the following Fig. 5).

Considering the stiffness and the precision required by the system the X and *U* axes are moved by using two motors in gantry configuration for each axis (X and *W* motors for X axis, *U* and *Q* motors for *U* axis).

The system can be moved in two ways:

Simple move mode: X, Y, U and *V* are moved separately, as programmed. This mode is used during service operations such as the keyboard load/unload.

Interlaced move mode: the *U* and *V axes* are configured as *slave* axes of the axes X and Y.

In this mode only the moves of the X and Y axes are programmed: *U* and *V* will copy the position of their own *master axes*. The copied position is obviously reversed in direction in order to follow the object/image rule.

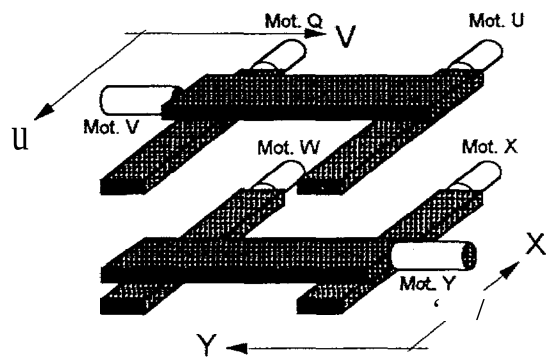


Fig. 5

This mode is used during the keyboard marking and therefore the synchronisation of the mask and the keyboard positions are accomplished in an easy way. Moreover this symmetrical move balances the stresses induced by the starting of the motors (both in acceleration and in deceleration) and consequently the errors due to vibrations are minimised.

The Flexible Numerical Control : The FNC was used for the axis and system control. The FNC is based on a Hw and Sw standard module i.e. the PC with the DOS operative system: since the environment in which it is being used is an industrial environment and consequently a lot of electromagnetic noise is present an industrial PC was used. The dedicated Software module was completely developed by RTM. The axis and I/O control boards are installed on the industrial PC which has the control of the whole system and therefore the axes, the external trigger to the laser, the e-valves are governed only by its CPU. The control Software was developed in *Borland C++* and *Lab Windows* (National Instruments) in order to have both the direct Hardware management and the easiness given by a powerful graphic user interface. For the axis control the PMAC board was used. This board can be considered a Numerical Control with its own language which allows to choose both the desired configuration of the axes, coordinate system, units, limit switches and the desired operation cycles such as axis movements, I/O operations, laser trigger and so on.

This board communicates with the PC by ISA bus for information exchanging and resources sharing (i.e. memory, HD, etc.). The PMAC is driven by a 40 *MHz* DSP able to manage up to 64 PLC programs and 8 multi-tasking movement programs: in particular this feature was use to synchronise the axis movement with the laser firing trigger. Moreover this controller is able to perform a very fast position loop (<100 *μs per axis*) and this allows to eliminate the speed loop in the motor controls. Since only the position loop is present the high speed value of 1 *m/s* with an acceleration of 0.9*G* were reached and therefore the cycle time was optimised. To control the system digital I/O (lamps, buttons, switches, etc.) an optoinsulated board was used; this board can manage up to 32 inputs and 32 output. The voltage level used is 24 *V* which allows to be protected against the electric noise.

The logical management of these signals is done by the PC with an interrupt every 1 *ms*.

The cycle digital I/O (laser sync., handling device pneumatic pistons, etc.) are managed by the PMAC board as programmed for the cycle in progress.

The same board manages the I/O which are dedicated to the axes such as the limit switches, the driver enables, etc.

The sensor.

The marking process requires an appropriate sensor system able to measure the contrast of the keycap being marked "on the fly". Three different configurations were studied and realised : **1.** Photodiode based sensor 2. The OFT based sensors 3. The CCD based sensor. The third configuration was chosen and installed on the marking cell.

1. *The photodiode based sensor* gives a signal ch is related to the radiation emitted[1] during the interaction between the excimer laser and the istic. The spectrum, the intensity, the temporal profiles of this radiation are dependent on the marking conditions and process parameters. In particular the signal dependence vs plastic parameters such as TiO_2 percecentage and surface roughness and process parameters (such as fluence) was found. The photodiode based sensor was *not* further investigated because the contrast measurement proved to be difficult.

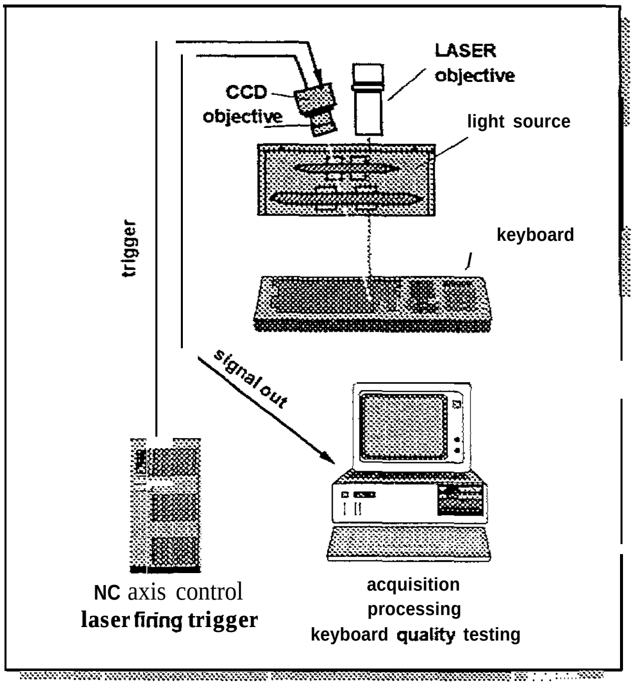


Fig. 6. The sensor installed on the cell.

2. The *OFT* technique gave encouraging results as resulted by PC simulations. Two different optical layouts the ***incoherent light 4f processor*** and the *coherent light Fourier processor* were studied.

3. The sensor we installed on to the marking cell was constituted by these parts:

- *The illumination device*
- *The CCD camera with the lens, the electronic module and monitor*
- *The vision board*
- *The PC and the program used to calculate the contrast*

The ***illumination device.*** The contrast measurement requires that the keycap surface being tested is illuminated in a homogeneous way. After many solutions were examined the best one was found and two circulars Neon tube lamps easily available and cheap were used. The two lamps have a power of 40 *W* each and the light is "white" and diffused.

The ***CCD*** *camera with* ***the lens, the electronic module and monitor*** The camera pickup device is an interfine transfer CCD with these main data:

. Model: SONY CCD Video Camera Module XC-77RR-CE	
• Picture elements:	756X581 (HxV)
• Sensing area:	8.8x6.6 mm^2
• *Scanning* system:	625 lines 2:1 interlace/non-interlace selectable with the switch
• Cell size:	11x11 μm
• S/N ratio:	54 *dB*
. Shutter speed:	from 1/52 to 1/2,360,000s in normal shutter mode
• Vibration resistance:	7 G
• Shock resistance:	70 G

Its lens is a 50 ***mm*** *f:1.8*. The magnification is 1:1.5 with an electronic shutter speed of 1/250,000. A dedicated b/w monitor displays the current image.

The *vision* ***board*** is a Cortex II which grabs the image taken with the camera. A dedicated Software is supplied with the board. The board was installed on an industrial PC completely dedicated to the sensor.To grab the image at the right moment the trigger was sent from the P-C of the Flexible Numerical Control.. When the board receives the trigger and after the Vertical Blank signal is received from the camera electronic module the image will be grab.

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[1] Particular care was taken to block the backscattered laser radiation (351 *nm*) from the photodiode active area.

The board converts each image pixel in a byte (8 bit) and uses the video RAM of the PC to reduce the time to process the data. These data are then read and processed by the program developed to measure the contrast in real time.

The PC and the program used to calculate the contrast: the PC is an industrial computer and the program to measure the contrast on-line was developed in *Borland* ***C++*** language and the graphic user interlace in *La bWindows* in order to follow the standard used in RTM . During the system start the software verifies some parts of the sensor (i.e. the presence of the camera, the correct set up of the Cortex II board and its functionality). The image sample is set in the low resolution mode (256x256 pixels) enough to contrast measurements.

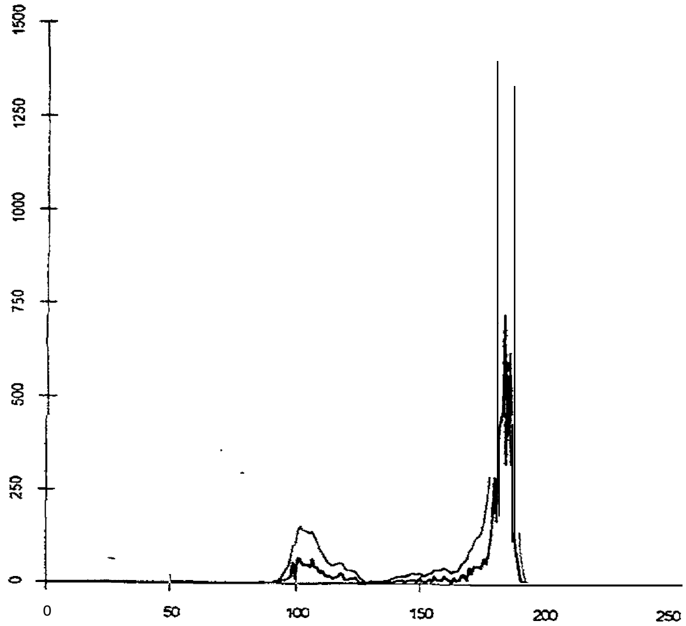

Fig. 7. Intensity distribution of the live and the filtered images.

The operations done by the algorithm are the following:

Loading of the database of the video windows: this database contains information about the areas to be analysed. These data are transferred from the Hard Disk to the PC RAM memory in order to enhance the speed of the system.

Waiting for the Vertical Blank: when this signal is received by the board the image is captured and analysed and the contrast analysis routine is run.

Algorithm The area in which the contrast has to be measured is not the whole captured image area (i.e. 256x256=65536 pixel=65536 byte) because it would require a large amount of calculations and consequently a too high processing time.

Therefore inside the video window (256x256 pixels) an analysis window is extracted; the upper left comer coordinates of the analysis window identify its position inside the video window. This position is different for each key; the coordinates are written inside the database of the video windows.

The Black ml-responds to the O [zero] level while 255 is the highest value of light. To eliminate errors a standard black is sampled in order to subtract the noise of the system.

The intensity distributions are stored in a vector matrix; each vector contains the number of points which have that intensity. In our algorithm the notation

distribuzione[125] =34

means that 34 points with the intensity level of 125 have been detected. All the vectors give the intensity distributions inside the analysis window.

Since the tune has a lot of peaks it is modified using a digital filter which smooths the curve. A typical intensity distribution for a key cap is given in the Fig. 30. Two curves are displayed. The bold curve is the real intensity distribution while the normal is the filtered one; it can be seen that in the filtered curve the peak are smoothed and the higher peak is enhanced. The Ratio is given by the following formula:

$$R = \frac{W - B_s}{B - B_s}$$

where: W is the white peak; B is the black peak; B_S is the standard black. At the end of the keyboard marking the ratio is known for each key so that the results can be printed, saved to a file, etc.

The marking cell.

The marking cell was constituted by the parts described. It was mounted and tested inside RTM excimer laboratory (see the following Fig. 8).

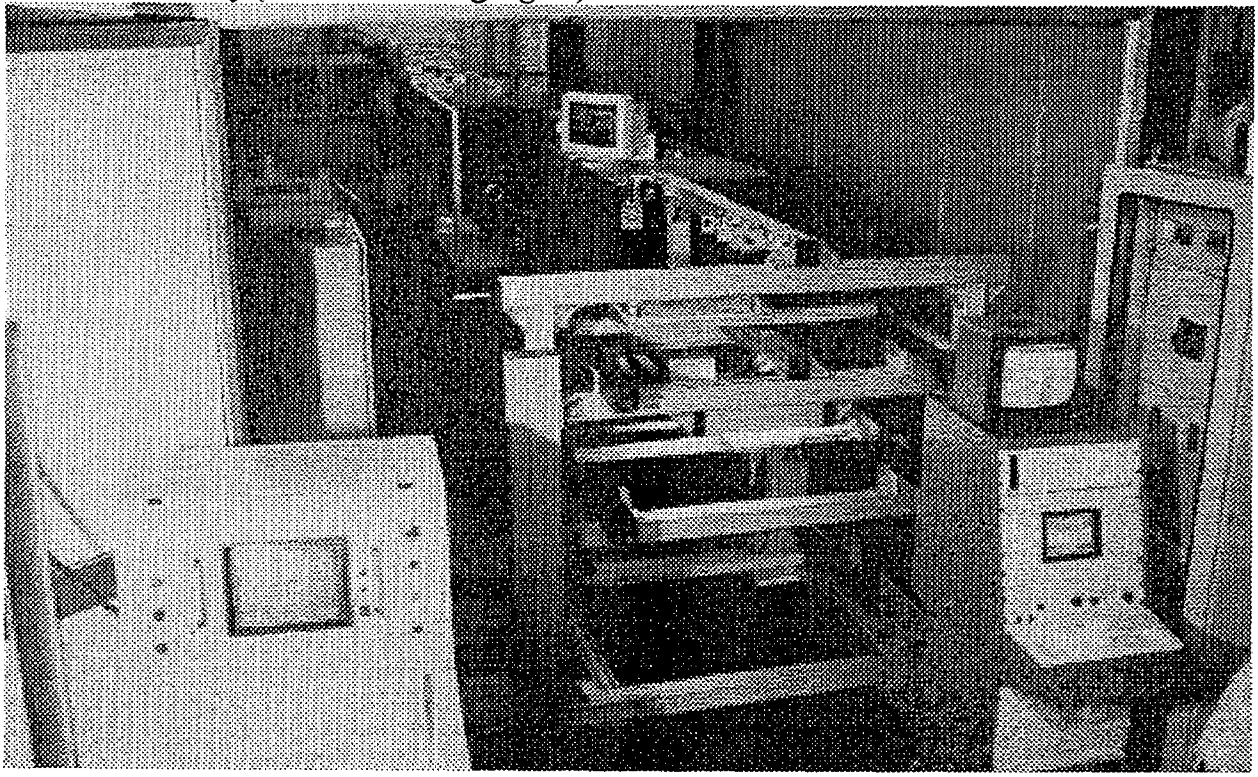

Fig. 8. In this photograph the whole marking cell is displayed

The Figure shows the whole marking cell. The left consolle is the consolle of the FNC while the right is the sensor consolle; the upper monitor placed onto the sensor consolle is the b/w one in which the live image of the key being marked is displayed and the lower is the monitor of the industrial PC dedicated to the sensor. Behind the two consolles there is the cell which contains the optical chain, some parts of the sensor (i.e. the

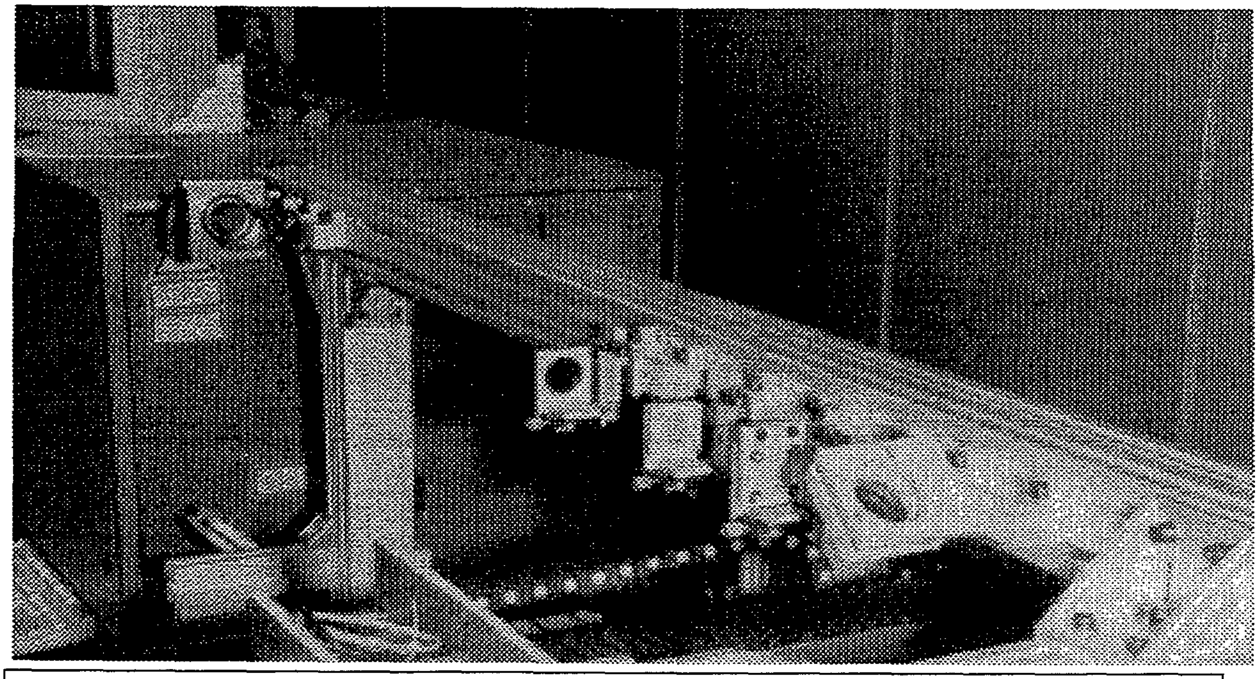

Fig. 9. Particular of the optical chain

illumination device and the camera), the mask and the keyboard holders and the mechanical units. Behind the cell the laser LPX 3 10i.
In the Figure 9 a part of the optical chain is displayed: the bending mirrors, the reverse beam expander, the fly's eyes and the mirror which bends the beam onto the mask are represented. Behind the LPX 310 *XeF* excimer laser. As can be seen the cell is constituted by a light but stiff structure built using aluminium sections. These sections have a particular shape which makes the assembling procedure easy.

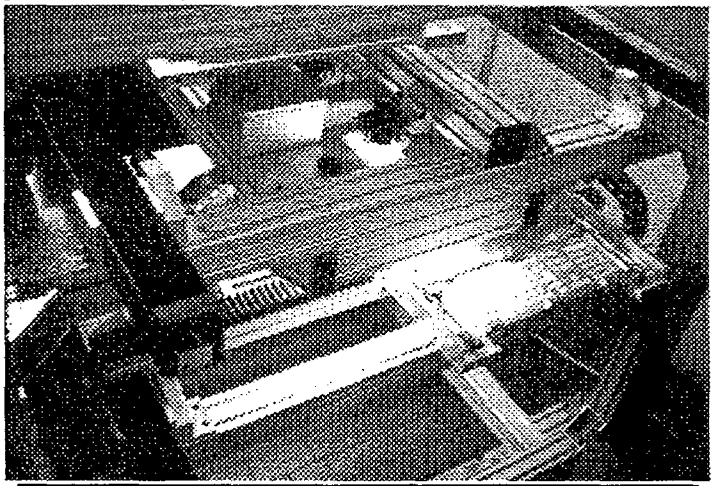

Fig. 10. Part of the making cell: the keyboard moving stage and the laser objective.

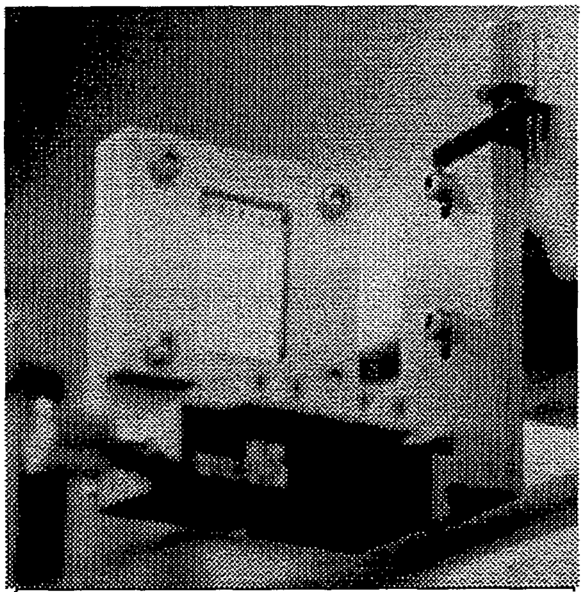

Fig. 11. This photograph represents the first of the two flv's eyes mounted onto the "marking cell.'

The constructed marking cell was used to mark the *ANK* 28 keyboard with the keys made of *ABS18* and *PS7*.
The cell was equipped with a pneumatic actuator which is able to pick the unmarked keyboard from the conveyor and to unload it after the marking has been carried out.
Moreover a metal protection guard is mounted around the keyboard which provides a shield for the operator from the laser backscattered radiation; a thick panel of *Plexiglass* (metacrylate ester) is mounted in front of the cell to shield the radiation scattered by the optical chain.

Results

The cell was equipped with an *Al* coated quartz mask on which the whole *ANK28* keyboard was etched. The coating showed to withstand the laser operating fluences (0.4 -0.65 J/cm^2) but the mask elements must be chosen with care (*Al* thickness, deposition technique, quartz surface preparation, chemical etching and so on). As part of this project an alternative mask technology comprising of etch patterning highly reflective multilayer dielectric films on quartz substrates to produce high laser damage threshold retitles was developed and tested. It successefully showed to withstanding high incident laser fluences with prolonged exposure to many tens of millions of pulses.
To efficiently transport the 351 *nm* laser radiation to the keyboard, a high transmission optical beam delivery system was designed and tested. A matched pair of spherical lenses were used to image relay the output of the laser onto the first array of the homogenisation optics. To provide a uniform beam for uniform marking of each character over its area, a-double fly's eye lens 'array homogeniser was used to split the beam into 40 beamlets that subsequently are overlapped on top of each other at the mask plane. Each spherical lenslet of this array had a rectangular shape matching the dimensions of the beam shape produced on the workpiece. Tests showed that with these optics 80% of the beam energy at the mask and workpiece planes had a uniformity with intensity deviations from the mean of ±5% RMS. The angles introduced by the fly's eye optical components were designed to match the

numerical aperture of the imaging lens so the effective coherence factor of the illumination system was close to unity.

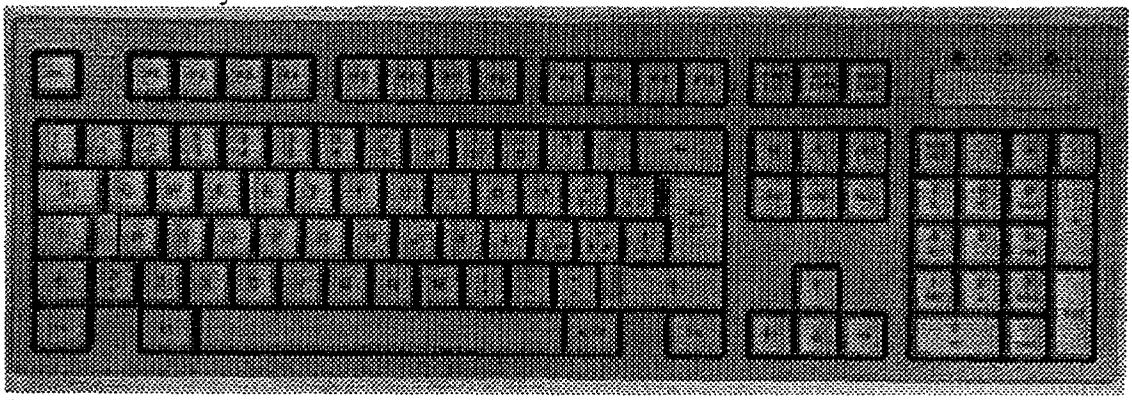

Fig. 12. The *ANK28* keyboard marked with the prorotype cell.

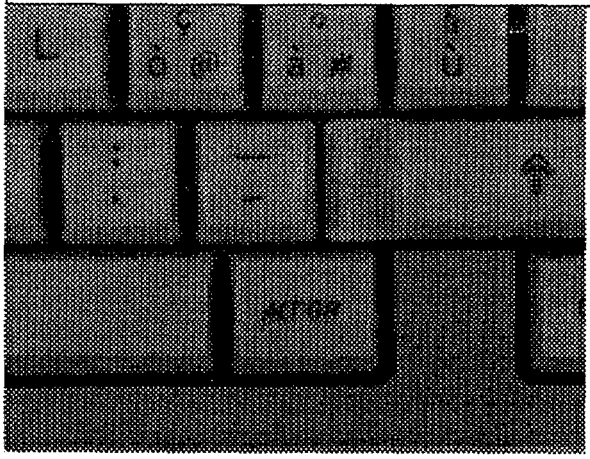

Fig. 13. Particular of the marked keyboard.

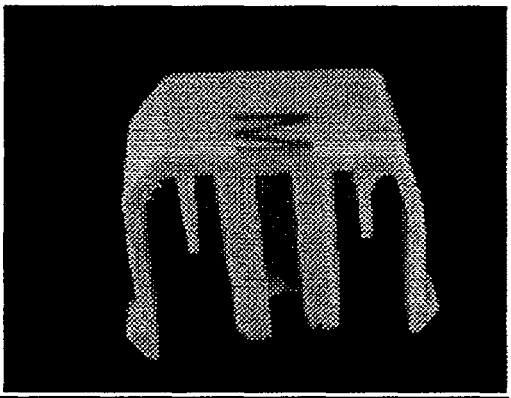

Fig. 14. The M cut to show the marking depth

Accordingly to the investigation phase, the mark contrast required, was reached using two pulses per unit area. The total marking time under this condition is 12.4 s. Since the production requirements states a total cycle time of 15s the available time for loading/unloading operation is 3.6 *s*.
The imaging mask technique produces high definition symbol. This aspect is essential for the quality required for computer keyboard.
Moreover the marking cell has a high flexibility because the keyboard layout maybe changed by only changing the quartz mask and loading two different configuration files the former for the FNC control and the latter for the sensor (database for the video windows - see page 11). This implies less stock costs.

To verify the results, inspections were carried out on optimised ABS. An **M** was cut as shown in the Fig. 13 to verify that the marking depth was as expected. The photograph depicted in Fig. 15 shows the mark depth in detail. The magnification factor is 112x. The dark band which corresponds to the mark depth is close to 100 μm. The dark zone, over this value, turns to white slightly. The mark depth is constant because the laser energy profile is homogeneous too. The fluence delivered onto the keycap is 0.42 J/cm^2 per pulse; the depth corresponds to the value measured during the tests performed onto the plastic optimisation.
The sensor was mounted inside the prototype cell as previously stated. It was able to work on-line and, for each keyboard, the key contrast was measured. It was able to detect the non optimised plastc keys (the ones which gave low contrast) substituted on purpose randomly on the keyboards, A graphic display shows the wrong marked keys to the operator and the results are stored on a data base for further processing.

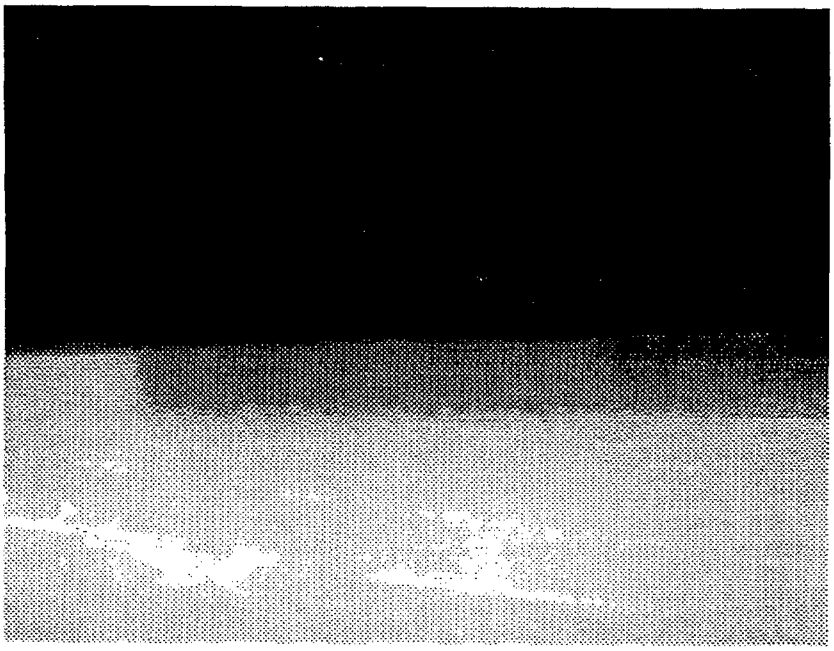

Fig. 15. The depth profile of the M cut.

Within this project the partners achieved good results; the marking cell showed to work efficiently, producing high quality excimer laser marked keyboards. Lambda Physik has developed the technical basis for a powerful and reliable *XeF* laser system for industrial keyboard marking; the new design concepts were evaluated in detail and an advanced industrial *XeF* laser has been outlined; Exitech developed an efficient optical delivery system with a double fly's eyes beam homogeniser included; Olivetti was devoted to the *PC/ABS*, *ABS*, *PS* plastic compound optimisation and related . tests required by the product specification; RTM constructed the on-line contrast measurement sensor, the marking cell structure, the moving stages and axis controls and provide to realise the S W/HW module; moreover metal coated mask were made by RTM and Olivetti together with the dielectric ones made by Exitech.

Conclusions

During the project novel concepts and components were developed that led to the final prototype excimer laser system capable of marking keycaps on computer keyboards at high speeds. The system architecture adopted was a novel synchronised mask-workpiece type that allowed exceedingly high process speeds to be achieved. Beam delivery components developed for the prototype marking cell included highly efficient beam relay, homogenisation and projection optics for operations at 351 *nm*. The prototype, integrated in RTM, marked the keyboard (*ANK28*) delivered by Olivetti both in *ABS* and in *PS*. The laser was installed in RTM on February 1995, the marking cell in May, the FNC and the motors and their adjustment in August, the complete beam delivery and projection system in September 1995 and the sensor at the beginning of October. The process parameters were found to mark the keyboards accordingly to the requirements. The mark time showed to be about 12 *s*, the cycle time less than 15 *s*. The quality control sensor was tested under operative conditions and was able to detect dummy faulty marked keys.
The successful demonstration of the fully integrated excimer laser keyboard marking workstation occurred at the final meeting on 30 and 31 October 1995.

Acknowledgements

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