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Rapid Prototyping of Polymer Microfluidic Devices Using CAD/CAM Tools for Laser Micromachining

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Abstract – A CAD/CAM system has been developed for rapid prototyping (RP) of microfluidic devices based on excimer laser micromachining. The system comprises of two complementary softwares. One, the CAM tool, creates part programs from CAD models. The other, the Simulator Tool, uses a part program to generate the laser tool path and the 2D and 3D graphical representation of the machined microstructure. The CAM tool's algorithms use the 3D geometry of a microstructure, defined as an STL file exported from a CAD system, and process parameters (laser fluence, pulse repetition frequency, number of shots per area, wall angle), to automatically generate Numerical Control (NC) part programs for the machine controller. The performance of the system has been verified and demonstrated by machining a particle transportation device. The CAM tool simplifies part programming and replaces the tedious trial-and-error approach to creating programs. The simulator tool accepts manual or computer generated part programs, and displays the tool path and the machined structure. This enables error checking and editing of the program before machining, and development of programs for complex microstructures. Combined, the tools provide a user-friendly CAD/CAM system environment for rapid prototyping of microfluidic devices.

Key Words **: Excimer laser micromachining, CAD/CAM, RP, Polymer microstructures, Microfluidic devices**

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1. Introduction

Microfluidic devices offer the opportunity to perform analytical experiments at the microscale level using lab-on-a-chip technology. The aspects of interest to researchers in the field include the material properties, processes to fabricate the devices at the microscale, and processes that can modify the material surface properties. Polymeric materials offer flexibility in terms of favourable material properties and ease of fabrication, compared to glass systems. Among the areas of interest to researchers are the development of rapid prototyping/fabrication techniques to achieve material compatibility, complex microstructures and microchannels, and reduced fabrication time and cost. In this paper we address the rapid prototyping issue.

In previously published work in rapid fabrication/prototyping, the level of automation and the use of computer-based tools has been limited. For example, Duffy et al. [1] developed a rapid prototyping method to produce polydimethylsiloxane (PDMS) moulds of complex microchannels for studying electroosmotic flow. Sandison and Morgan [2] developed a rapid fabrication procedure for producing multi-layer micro-channel networks, whereby they produced stamps using a dry film photoresist which were used for hot embossing of polymers such as polymethylmethacrylate (PMMA) and polytetrafluoroethylene (PTFE). Narasimhan and Papautsky [3] produced microchannels with their rapid method of fabricating hot embossing tools using PDMS, which were then used to fabricate microchannels in PMMA.

Excimer laser micromachining is another fabrication process which can be used for rapid prototyping. While laser micromachining provides a unique capability, achieving complex textures and specific 3D shapes is difficult because of the lack of computer aided tools to improve the efficiency of the design and fabrication stages.

Microstructuring with excimer laser ablation is normally achieved by using non-contact image projection techniques. These techniques require custom-made chrome on quartz photo masks as tools for shaping the

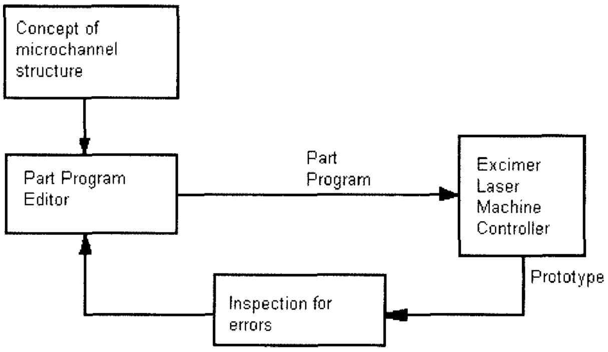

Fig. 1. Conventional practice for creating part programs for laser micromachining.

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beam to produce the desired structures. These masks are relatively expensive and making them for every change in design is not practical. Furthermore, the ablation process is driven and controlled by Numerical Control (NC) part programs which are currently written manually to achieve the desired microstructure shape. The part programming cycle from creating the program through to the prototype stage is illustrated in Fig. 1. The creation of the part programs is a time-consuming process, relies on operator expertise, uses a trial-and-error approach to produce a program for a desired shape and to optimise the appropriate machine parameters to achieve the required surface finish.

2. Related Work

As mentioned previously, research in the development of computer-based tools for rapid prototyping in microfludics has been limited. This is also the case for laser micromachining, which has concentrated on mass-fabrication using simple programming strategies, and has neglected the automation of the rapid prototyping function. This is partly due to the novelty of the technology and the heavy emphasis on expanding the applications. The past research effort at developing CAD/CAM tools for laser micromachining is presented below.

Tonshoff et al. [4, 5] developed a 3D-CAD interface for micromachining with an excimer laser. They developed a special CAD/CAM software that includes the excimer laser specific aspects of workpiece modelling and the process itself. Furthermore, strategies to minimize the processing time using flexible laser beam shaping with an NC mask were implemented. In regards to single ablations with a varying shape and depth, a special path calculation was programmed that reduced processing time.

Krishnan and Nassar [6] used an integrated excimer laser microfabrication system for direct drawing-to-production of photo-ablated microstructures. Their system consists of an excimer laser (248 nm and 351 nm), high-resolution stages, CAD system, and a visual observation and real-time metrology system. The material for the process was selected depending on the required edge wall definition, aspect ratio, surface roughness, debris formation and ablation threshold.

Perkins' [7] research overcame the limitations of the control software for an Exitech LTD Series 8000 micromachining workstation. The controller had a limit of 64 kilobyte in the size of part program that could be processed, while the CAM module could generate larger programs. Perkins developed a stand-alone software and incorporated a limited version of the software into a commercial CAM package (AlphaCAM) using Visual Basic for Applications.

Stassen Boehlen et al. [8] developed a CAD/CAM software to automatically generate tool path according to a CAD drawing of a MEMS device. They based their system on an existing software (AlphaCAM by Licom Systems Ltd). Simulated 3D representation of removed material is achieved using conventional machining strategies such as pocketing operations. Subsequently, tool paths are translated into CNC commands to create the part programs.

The above review illustrates important, but limited, research that has been carried out to develop CAD/CAM tools. The following describes several Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) tools that have been developed [9-13] and facilitate rapid prototyping of microfluidic devices. The tools have undergone several years of development, and for the first time, have been presented together as a complementary set of tools. The functionality and features of the tools differ significantly from those reported in [4-8].

3. CAD/CAM Tools Development

Here, a set of tools has been developed which together provide a number of advantages over previous CAD/CAM systems. The advantages and benefits include: user-friendly interfaces, use of standard data formats, tailored algorithms developed for the laser ablation process and its parameters, provision of a material and process database, use of standard CAD models of microstructure for part programming, and part programmer generation and verification. Existing CAD/CAM systems have some, but not all of the above features. The set of tools provide a user-friendly environment with the following major functions:

1. Use a CAD model of a microstructure to automatically generate a part program to drive the laser machine controller;
2. Process parameters stored in a library can be included in the program when generating the part program to optimise performance;
3. Use a simulation tool to generate a 2D or 3D model using a part program to compare with the original

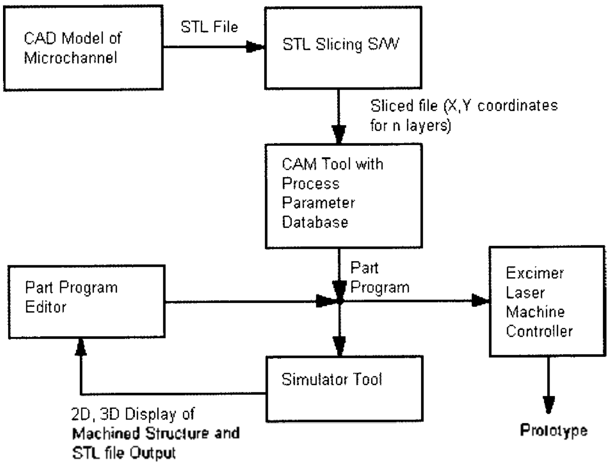


Fig. 2. Rapid prototyping cycle using the CAD/CAM tools.

CAD model, or as a check on the integrity of the program.

The above functions are illustrated in Fig 2. Functions 1 and 2 are performed by the CAM Tool, and 3 by the Simulator Tool.

3.1 Part Program Generator (CAM Tool)

Referring to Fig. 2 the first step in the process is to create the CAD model, then convert the CAD model file into an STL format. The conversion to an *.stl* file can be achieved using a standard commercial CAD graphic package. A slicing algorithm (InsightV2.1™) was then used to create a "slice file" (*.sgm*), which is a series of layers, and divides the 3D model into a series of 2D cross-sectional areas. Each layer represents a cross-section of the 3D model of finite thickness. A layer is a collection of the 2D vertices (*X*, *Y* coordinates) that define the boundary of the part and all vertices have the same value of Z-coordinate. In the next step, the slice file is converted into a part program using a set of algorithms (reported previously [13]). The algorithms use various strategies for tool path optimization using the optimum values for all process parameters involved. The software was designed to work with 10x reduction via the imaging lens and provides a resolution of 10 μm square.

The four steps of the CAD/CAM process are summarized in Figs. 3, 4, and 5.

First Step: The 3D model of a corner cube structure (Fig. 3) that we wished to machine was created using the SolidWorks® (SolidWorks Corporation) CAD package which has the option to export this model as an STL graphics file format (ASCII or Binary).

Second Step: This step represents the shape of the object as a mesh of tiny triangles laid over the surfaces. The triangles must meet up exactly with each other, without gaps or overlaps, if the object is to be built successfully. The "slice files" (Third Step) which are used to build each individual layer are calculated from the STL file (Fig. 4 (a)), and if there are any gaps between the triangles, then the edges of the slices are not properly defined [14].

Third Step: The representation of a 3D structure in STL file form is suitable for input to the InsightV2.1™ (Stratasys Inc.) FDM (Fused Deposition Modelling) software for slicing into a layered structure (Fig. 4). The slicing file is created in a format that contains the original information from the CAD model and is a collection of the 2D vertices where all vertices that

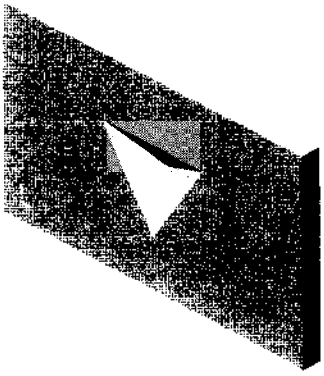


Fig. 3. 3D model of a corner cube (base triangle side length 4.7 mm) structure on a surface.

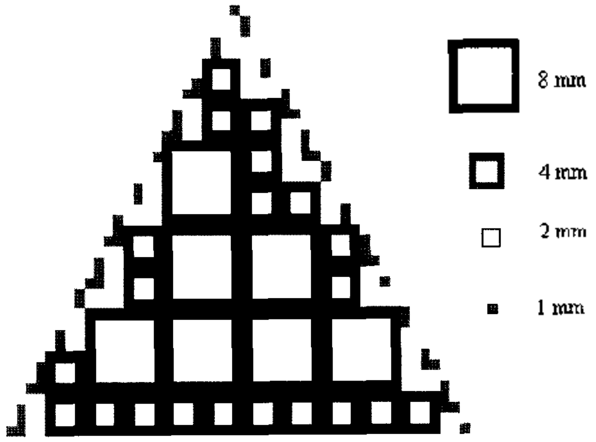


Fig. 5. Mask layout for a layer of corner cube structure produced by four different sizes of square masks.

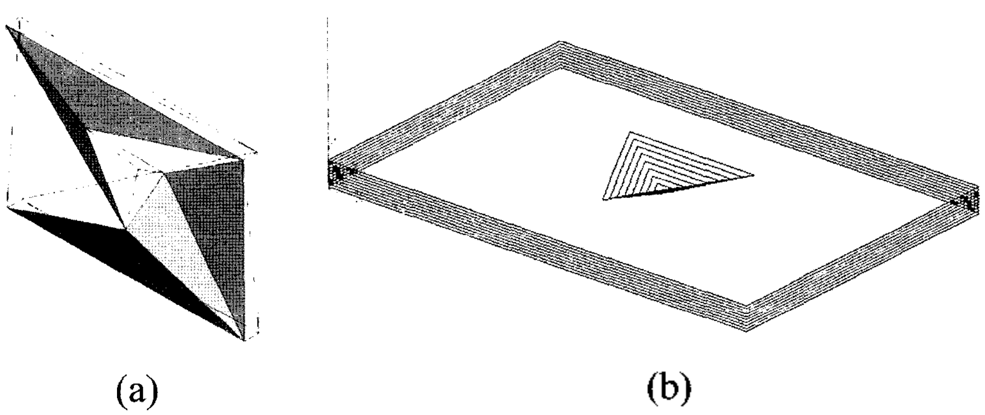


Fig. 4. (a) Triangular tessellation view of the corner cube structure shown in Fig. 3, (b) Sliced representation of the corner cube structure.

belong to the same layer have the same value of Z-coordinate. Each layer represents a cross-section of a 3D model, and the layers are shown in Fig. 4 (b).

Fourth Step: The layered structure is used as an input to the CAM system to create the tool path for the excimer laser ablation tool controlled by a CNC system (Unidex 500 Controller, Aerotech Inc.). Using this information, our software automatically generates the NC code to be executed for micromachining. A cross-sectional area to be machined of the corner cube of a layer of the 3D model with different size masks layout was produced by the system (Fig. 5).

Another feature of the system is the tool path algorithm which determines the directional information and point-to-point coordinate data for material removal within a given area. Three different types of algorithms (Left-to-Right, Zig-Zag and Star) for optimal tool path generation were developed and these are illustrated in the Figs. 6 and 7. The Left-to-Right and Zig-Zag algorithms are used in conventional Computer Numerically Controlled (CNC) machining [15]. Each approach has its own advantages and disadvantages, but the best possible results are achieved with the Star path Algorithm.

The Left-to-Right algorithm works out the best possible masks, layout and area to be machined. The Left-to-Right algorithm was developed to scan the area to be machined always from one side of the substrate. Starting at the top, after one row is scanned the laser head moves to the next row, but scanning always starts first from the same side as in the previous row as shown in Fig. 6 (a). One of the problems with this approach is that masks could not be laid out without leaving gaps in the structure.

The Zig-Zag algorithm works in a similar way, but the masks are laid out in a consecutive manner, row by row. The algorithm scans in advance the predetermined area in a Zig-Zag fashion. The machining area is scanned from both sides as shown in Fig. 6 (b). This algorithm had a similar problem and gaps appeared in both directions. However, the advantage of this approach is that it halved the processing time.

A star algorithm resolved the problem of the gaps in mask layout that appears with other two algorithms as a result of using a standard set of square masks (8, 4, 2, 1 mm) to approximate any surface. If the area to be machined cannot be represented with a combination of the above-mentioned range of masks, gaps in designed structure will appear in mask layout and consequently cause errors during machining process. The algorithm starts the layout of masks always from the centre of the area to be machined and moves outwards. This ensures that the largest possible size masks are concentrated around centre of machined areas (see Fig. 7), and the smallest masks are around the borders of machined regions. This improves the surface roughness, especially for symmetrical structures, because the number of shots to produce the structure will be minimal, thereby reducing machining time, and stitching errors effects will be evenly distributed for the particular masks range used.

Fig. 7 illustrates for the star algorithm layout how this

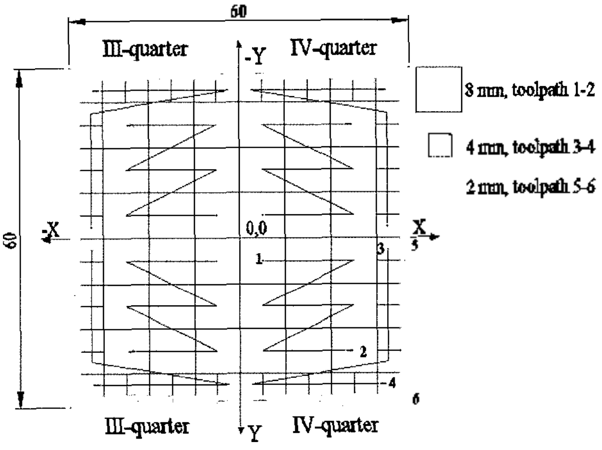
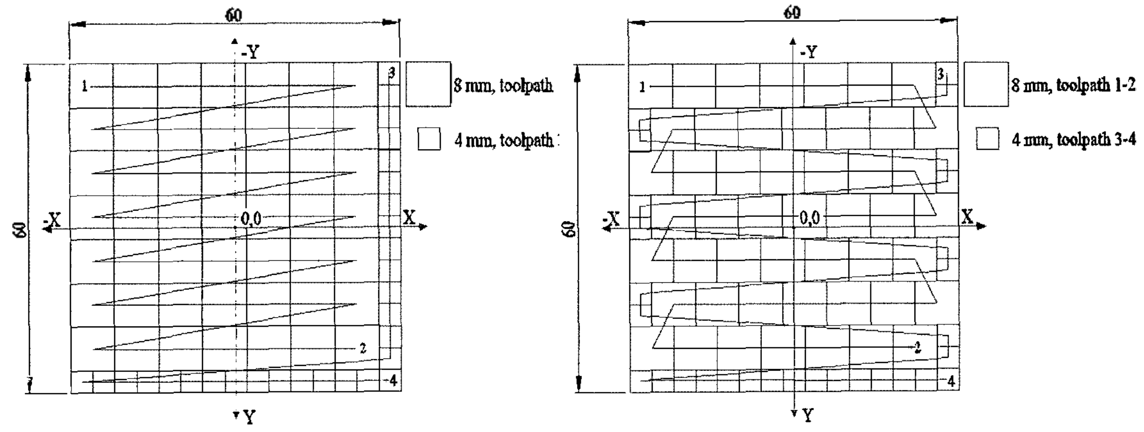


Fig. 7. Star algorithm showing tool paths generated for each quarter of the structure for 8, 4, and 2 mm mask sizes.



(a) (b)

Fig. 6. (a) Left-to-Right Algorithm (Top to Bottom), (b) Zig-Zag Algorithm.

algorithm was used to layout the masks for machining of 6x6 mm square structure at the workpiece after 10x reduction by the laser optics. First, the algorithm starts the layout with the maximum available mask size, 8mm, and generates tool path 1-2 in the first quarter of the structure. Second, the next size down mask is used, 4mm, to generate tool path 3-4, and finally, the 2 mm mask is used to generate tool path 5-6. From Fig. 7 it is noticeable that the smallest possible mask size, 1 mm, was not needed to produce this particular square structure. Compared to the other two strategies, this strategy minimises the edge (contour) error because the algorithm always lays out the smallest possible mask size at the border of the structure.

Experimental machining trials [13] were conducted to verify the performance of the algorithms, and the resulting microstructures agreed with the simulation results.

Complex structures were previously difficult to achieve with existing methods without the use of a dedicated mask. The use of multiple masks provides flexibility and enables complex microstructures to be easily produced.

The CAD/CAM system enables researchers to focus more on the design of 3D microstructures by making use of the CAM module to create part programs. The CAM module automatically converts the CAD model into NC code, and with user assistance, incorporates process parameters and other necessary data. The main features and limitations of the system are outlined below.

Software Features

- Standard set of multiple mask sizes
- 10 to 8,000 μm square mask size
- Inclusion of a laser cleaning cycle for removal of ablation debris
- Machining with less shots per pass and multiple pass control
- Database with stored optimal machine data
- Uses of standard STL file format of 3D CAD model of a microstructure as an input.
- Materials in the database include process parameter information for polycarbonate (PC) and Polyethylene Terephthalate (PET).
- Process parameters include: fluence for a depth of cut; side wall angle; stitching/overlap error; surface roughness; pulse repetition frequency (PRF); mask shape and size; mask dragging effect; machining time.

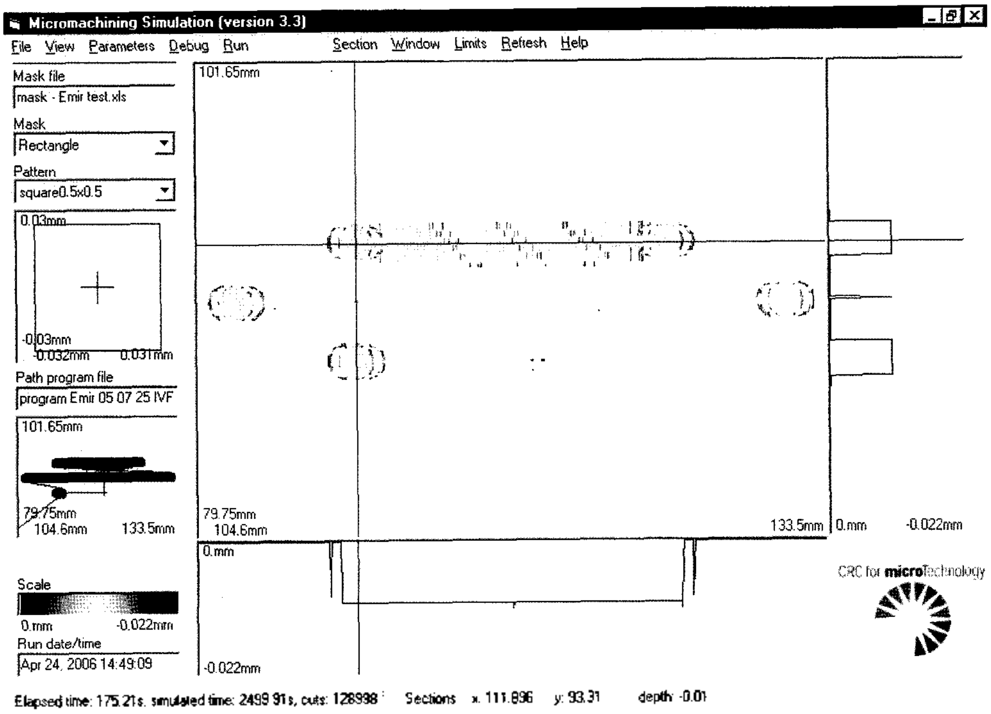
Software limitations

- Currently algorithms developed only for the square and hexagonal shape mask tools.

3.2 Part Program Verification (Simulator Tool)

The simulation tool reads NC part programs and displays the 3D machined surface. The tool can cope with the large programs with thousand of lines of instructions for complex parts.

Part programmers take time to write the NC code programs manually, and rarely get it 'right the first time'. With this simulation tool, the part programmer works more effectively by being able to view and check the program using the simulation tool before trialling it using time on an expensive laser micromachining tool. The simulator also allows a user to investigate various paths and other parameters used in the development of



Mask file: mask - Emir test.xls
Mask: Rectangle
Pattern: square0.5x0.5
Path program file: program Emir 05 07 25 IVF
Run date/time: Apr 24, 2006 14:49:09

```
Elapsed time: 175.21s. simulated time: 2499 91s, cuts: 128938   Sections  x. 111.896   y: 93.31   depth: -0.01
```

Fig. 8. Micromachining simulation tool interface showing device simulated.

novel microstructures for texturing or patterning. Alternatively, the program to be verified can be created using the CAM tool mentioned previously.

The graphical user interface (GUI) for the simulation tool is shown in Fig. 8. In a simulation, a part program is first read in. The laser path defined by the NC-code is plotted in the path window shown in the left-hand side of the interface. The required mask patterns are read directly from Microsoft Excel worksheets. The spreadsheet format allows for parametric definition of patterns enabling families of patterns to be easily specified. A selected pattern outline is shown in the pattern window and the patterns for each mask can be scrolled in the window. Multiple patterns can be used in the one simulation. In the software, these are selected through a comment statement in the part program rather than through the mask position relative to the laser.

The workpiece surface is modelled as a grid or raster of points. On each laser cut, the pattern is positioned on the workpiece grid and the laser cut depth is subtracted from the grid. The machined surface is plotted in 2D in the main window of the interface at the end of each simulation. The depth is indicated as a grey or colour scale as selected and the intensities can be varied to promote features of the image. Horizontal and vertical depth sections of the grid as shown in Fig. 8 can be made on the fly. The grid can be windowed and rescaled for higher accuracy modelling. The simulated micro-machining time and number of laser cuts is summed during the simulation.

The ablation rate is set as a constant for each simulation. A future extension could be to include a database of material properties versus laser fluence rates to predict machining rates.

Parameters specific to the laser micromachining operation are read in from a configuration file. These include parameters such as maximum and default feedrates and defaults for machine settings.

Parameters specific to a user's operation of the simulation tool can be saved to a user profile and automatically retrieved on simulation start-up. These include parameters such as working file directory, scaling defaults, cut depth on each cut, pattern demagnification factor, laser beam width, and grid default settings.

To assist in debugging, the part program can be stepped through and the grid re-plotted when required. The debugging interface shows various parameters and buffered NC-commands for each step. The simulation tool checks the code on each pass for likely programming errors such as coding errors (for example, incorrect commands) and logic errors (for example, attempting to fire the laser faster than the repetition rate set). The part program path plot can also assist in error detection. The path can be plotted to a larger window for better viewing. Co-ordinates can be displayed for select locations in each window of the interface.

The grid and sections can be exported in various formats for further evaluation and reporting. These include exporting:

- images for simulation and sections as bitmap files (.bmp) files.
- sections to text (.csv) files for further analysis/graphing using, say, a spreadsheet.
- grid to a location (.stl) file for import to a viewer for 3D interactive viewing. Depth scaling can be specified on export to assist in viewing small depth machining. A large number of applications are available to provide 3D viewing of these files.

To demonstrate the capability of the CAM and simulator tools, a particle transport device was manufactured. The device has a complex arrangement of microchannel networks and would present a challenge if it were to be prototyped using the manual approach.

3.3 Design, Fabrication and Process Simulation

A particle transportation device was designed and fabricated to demonstrate the performance of the CAD/CAM tools. The microfluidic device incorporates a network of microchannels and obstacles. Barriers in the main channel are used to direct the flow of particles, while allowing a relatively unimpeded flow of the carrier fluid. A CAD model of the various components of the final assembly is shown in Fig. 9 (a). The chip with the microchannel network is the focus of the case study, and a 2D schematic of the microfluidic device is shown in Fig. 9 (b). The polycarbonate chip with the microchannel network forms one part of the complete device, and in a subsequent and separate process, a cover is bonded to the top of the device to seal the open channel network.

Automated Part Programming

A CAD model of the device was created and then its *.stl* file was used by the CAM tool to generate the part program. The mask used in machining had a 0.5 mm square pattern which was reduced to a 50 μm image size at the workpiece. The system generated a part program with 10,734 lines of NC code to produce the device.

The process parameters used to complete the part program are listed below:

- Etch rate used for PC at fluence 1.1 J/cm^2 (equal to 0.40 μm/pulse)
- Number of shots to achieve 10-micron depth was 25.
- Beam size at the workpiece was 0.05 mm
- Workpiece stage velocity was 6 mm/min
- Psod (position synchronised output distance) value was 20

The device was machined, and an image of the main channel, with the three columns of staggered square barriers, is shown in Fig. 10 that was taken using a laser scanning confocal microscope (Olympus OLS1200). The barriers direct the flow of particles towards one side of the channel and restrict the particle size that can travel through the channel to less than 100 μm. The

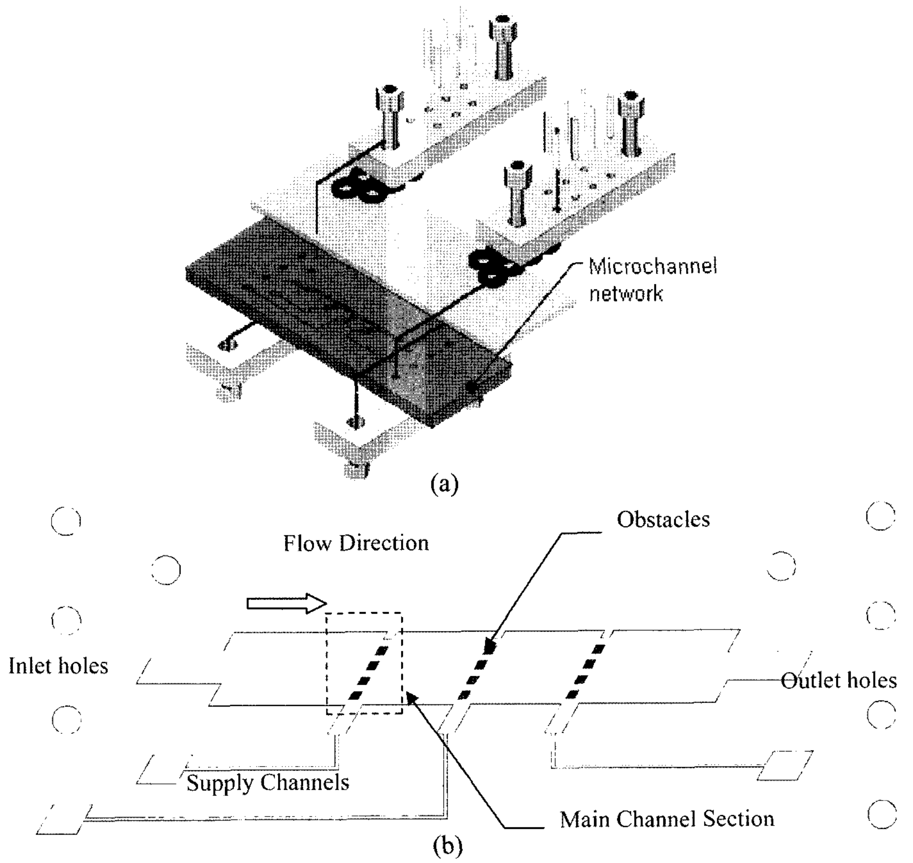


Fig. 9. (a) CAD model of exploded view of particle transportation device assembly with microchannel network component indicated (chip dimensions are 75 mm × 25 mm). (b) Schematic of a microfluidic device for particle transportation.

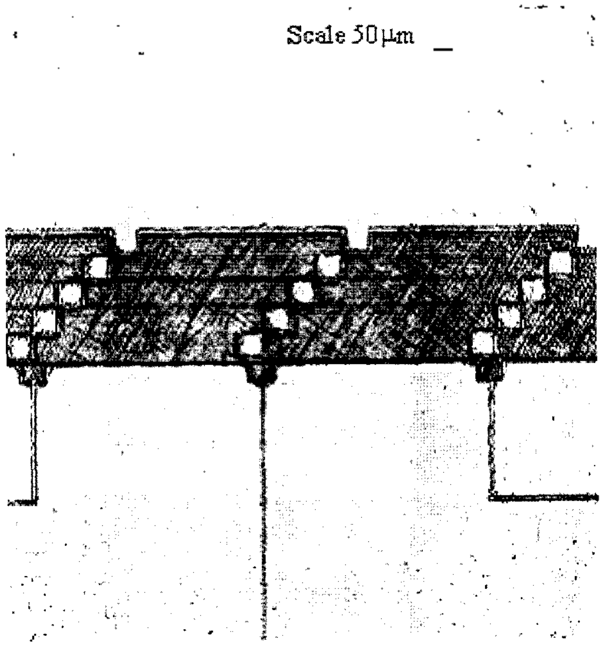


Fig. 10. Microfluidics device for particle transport.

CAD model design depth was 10 μm, and the machining depth was measured to be approximately 12 μm. The machined microchannels showed good agreement with the CAD model and measurements verified the accuracy of the CAM tool.

Simulation Tool and Part Program Verification

In laser micromachining, each laser pulse ablates a relatively uniform thickness of material from the surface of the workpiece within the projected pattern outline. The cut edge slopes at approximately 7°, which is caused by reflection and refraction of the laser by the workpiece material. This slope varies with depth when repeated cuts are made in the one position.

The simulator assumes the laser to have a uniform ablation rate, which is a reasonable approximation to the micromachining process, and the edges of the cut are assumed to be vertical to simplify the modelling. The NC code part program defines the path of the pattern movement relative to the workpiece and the position of the pattern at laser firing. For the simulation, the workpiece is represented as a grid or raster. At each laser firing a uniform thickness is subtracted from those grid points that lie within the pattern outline.

The simulation tool interface is shown in Fig. 8. The grid of depth is displayed in 2D in the main window of the graphic user interface (GUI), and shows a 2D picture of the microfluidic device. The particle transportation device is shown modelled in a plan view. The grid information can then be exported as an *.stl* file for displaying as a 3D model.

Sections through the particle transport device are also shown on the GUI. The cut depth or ablation at each laser firing is dependent on the laser fluence and also on the depth. The simulator assumes that the cut depth will be the same at each firing and is set as a simulation parameter. For this simulation the cut depth for each laser pulse was adjusted to give the measured channel depth (1.2 μm ablated per pulse). Other features shown in Fig. 8 include:

- Vertical and horizontal cross-sections are displayed in graphs in the right and bottom windows and are controlled through the movable cross-hairs on the main window. A numerical depth scale is shown in both windows, in this case 0 to 22 μm, and the indicated section has a machined depth of 10 μm. The *X,Y* coordinates of the cross-hairs, and depth, are shown at the bottom of the screen.
- Tool path is drawn as a line trace and is shown in a window above the depth colour scale on the left.

The grid was exported from the simulation tool as an *.stl* file and viewed in three-dimensions in a CAD system or *.stl* editing tool (e.g. STL Editor from Floating Point Solutions), and is shown in Fig. 11. Good agreement is shown in a comparison between Fig. 11 with the schematic in Fig. 9.

4. Conclusions

Compared to conventional CAD/CAM technology, few computer aided tools to assist laser micromachining are available, and research to develop such tools has been limited. The research reported here, and elsewhere, by the authors, has used approaches from conventional CAD/CAM and RP technologies to develop CAD/CAM tools which simplify part programming and enable rapid prototyping of microfluidic devices.

The major requirements in laser micromachining are part programs, masks and process parameters. All these requirements were previously determined using a relatively slow approach in comparison to conventional automated systems. Part programming has been simplified by enabling CAD models to be used to automatically generate the programs. Also, results from previous experimental studies on multiple masks, overlap error compensation and optimised process variables for two polymer materials have been incorporated in a CAM tool. The CAD/CAM system was tested by machining various simple microstructures in previous work, and demonstrated here, by machining a complex microchannel network of a particle transportation device.

A complementary software, the simulator tool, was also developed to simulate the tool path of a part program. The simulator tool accepts manually or computer generated part programs (NC code), and creates a graphical representation of the laser tool path. This enables error checking and editing of the program to be done before it is used on a machine. Alternatively, the tool may be used to design complex microstructures. The simulator also allows the depth of ablation to be checked numerically and graphically. 2D and 3D display, with screen manipulation and *.stl* file export features, are also provided.

In combination, the tools provide a user friendly CAD/CAM system environment for laser micromaching that facilitates rapid prototyping of microfluidic devices.

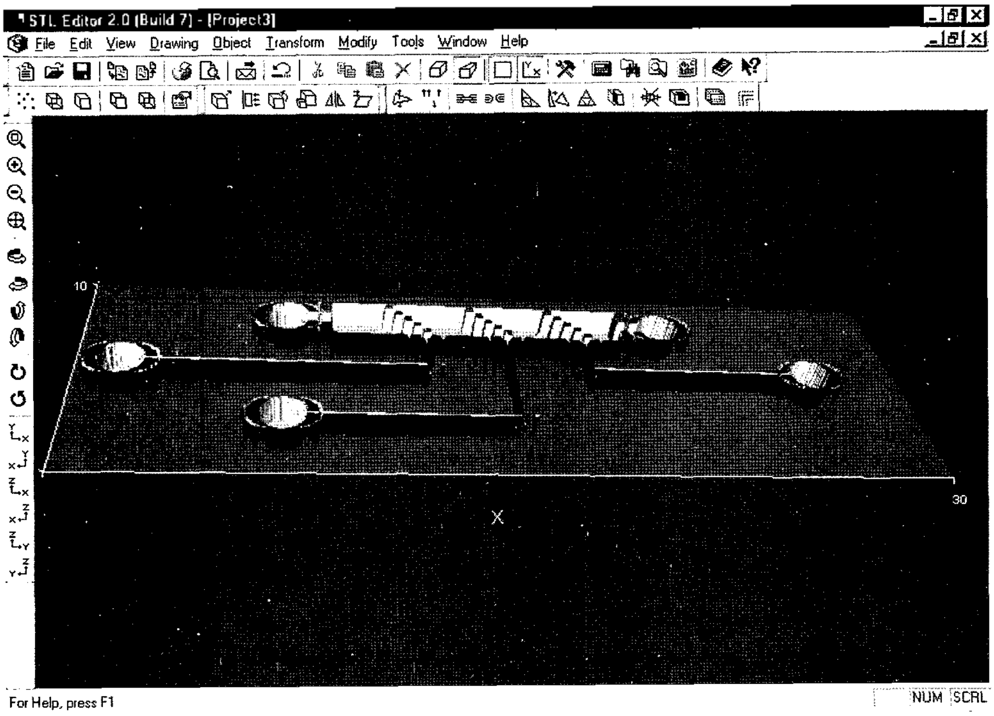


Fig. 11. A 3D view of particle transportation device as modelled by the simulator.

5. Acknowledgements

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References

[1] Duffy, D. C., Schueller, O. J. A, Brittain, S. T. and Whitesides, G M., (1999), Rapid prototyping of microfluidic switches in poly(dimethyl siloxane) and their actuation by electro-osmotic flow, *J. Micromech. Microeng.* **9**, 211–217.

[2] Narasimhan, J. and Papautsky, I., (2004), Polymer embossing tools for rapid prototyping of plastic microfluidic devices, *J. Micromech.'Microeng.* **14**, 96–103.

[3] Sandison, M, E, and Morgan, H., (2005), Rapid fabrication of polymer microfluidic systems for the production of artificial lipid bilayers, *J. Micromech. Microeng.* **15**, S139–S144.

[4] Tonshoff HK, Graumann C, Hesener H, Rinke M, (1998), NC-controlled production of smooth 3-D surfaces in brittle materials with 193nm Excimer Laser, Micromachining and Microfabrication Process Technology IV , SPIE Vol. 3511 Conference Proceedings, 56-66.

[5] Tonshoff, H. K., von Alvensleben, F. and Kulik, C., (1999), Advanced 3D-CAD-interface for micromachining with excimer lasers, Design, Test, and Microfabrication of MEMS and MOEMS, SPIE Vol. 3680 Conference Proceedings, 340-348.

[6] Krishnan, A. and Nassar, R., (1998), Rapid prototyping using excimer laser microfabrication system, Materials and Device Characterization in Micromachining, SPIE Vol. 3512 Conference Proceedings, 374-385.

[7] Perkins, D., (2000), CAD/CAM systems for an Excimer 8000 Series Laser Micro Machining System, MEng (Honours) Dissertation, Computer Systems Engineering, University of Wales, Bangor.

[8] Stassen Boehlen, I., Fieret, J., Holmes A. S. and Lee K. W., (2003), CAD/CAM software for an industrial laser micro-manufacturing tool, SPIE Vol. 4977 Conference Proceedings, 198-206.

[9] Mutapcic, E., Iovenitti, P. and Harvey, E., (2000), A 3D visualization tool for Excimer laser micromachining, Smart Materials and MEMS, SPIE Vol. 4236 Conference Proceedings, 230-241.

[10] Hume, R.G., Iovenitti, P. G., Hayes, J. P. and Harvey, E., (2002), Simulation of Excimer Laser Micromachined 3D Surface using a CAD Solid Modelling Package, Symposium Proceedings on Smart Structures, Devices, and Systems, SPIE Vol. 4935, 436-444.

[11] Hume, R. G., Iovenitti, P. G., and Harvey, E., (2003), CAD Simulator for Excimer Laser Micromachined 3D Surfaces, *mstnews* 2/03, 43-45.

[12] Mutapcic, E., Iovenitti, P. and Hayes, J. P., (2005), A prototyping and microfabrication CAD/CAM tool for excimer laser micromachining process, *The International Journal of Advanced Manufacturing Technology*. In press (Published online 24November 2005).

[13] Mutapcic, E., Iovenitti, P. and Hayes, J. P, (2002), Automated generation of NC part programs for excimer laser ablation micromachining from known 3D surfaces, Symposium Proceedings on Smart Materials, Nano-, and Micro-Smart Systems, SPIE Vol. 4935, 445-453.

[14] Oxley, A., (1985), Surface fitting by triangulation, *The Computer Journal* (28/3), 335-339.

[15] Chang, C-H., Melkanoff, M.A., (1989), *NC machine programming and software design*, Prentice Hall.

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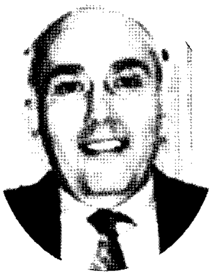
Emir Mutapcic



Pio Iovenitti

Richard Hume

Jason Hayes