6th International and 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR-2016), December 16-18, 2016 at College of Engineering., Pune, Maharashtra, INDIA.

Scope and evolution of micro EDM in Texturing and Structuring applications

Ganesh Malayath,[1], Ajay Sidpara*[2], Sankha Deb[3]

[1]*Mechanical Engineering department, IIT Kharagpur*

[1]ganeshmalayath@gmail.com,

[3]sankha.deb@mech.iitkgp.ernet.in

Corresponding Author Email - [2]ajaymsidpara@mech.iitkgp.ernet.in

Abstract— **Micro EDM gained popularity in the field of micro manufacturing due to various advantages likeforce free machining, stringent control over the feature geometry and economical compared to other manufacturing methods. For making the patterns for micro casting and fabrication of 2D/3D micro features on the desired materials, micro EDM can be used instead of lithographic techniques or any other micro fabrication methods. In this paper, the scope of micro EDM for fabrication of micro pillars for collecting and sorting the biological cells, micro channels with micro pillar-structured walls for blood separation devices, injection mold Inserts for fluidic channel are discussed. This paper also presents the evolution of micro EDM in the field of manufacturing arrayed micro-features on metal surfaces, making composite three dimensional microelectrodes and micro-cavities, micro structuring with laminated micro-electrodes on metallic glass, and fabricating hydrophobic and anti-icing surfaces.**

Preliminary experiments are done to investigate the dimensional accuracy of micro EDM.

***Keywords* - Micro EDM, Structuring, Texturing**

1. INTRODUCTION

Fabrication of micro components became a necessary part in bio medical; telecommunication; automotive industries, whichbecame a driving force for large advancements in manufacturing strategies including micro-cutting, micro-grinding, micro-milling, micro-EDM, micro-ultrasonic machining, micro laser beam machining technologies and lithographic processes. Utilizing these technologies, the production of micro slots, 3D micro structures, and other complex geometries in miniaturized form became easier and viable. Lithographic processes are the most popular micro machining method among them for the fabrication of micro components. The fabrication of 3D or freeform surface using lithographic techniques is very difficult and expensive because of the need of mask fabrication. The flexibility in design is very small and modelling of these processes is very complex. The alternative machining techniques are mechanical micro milling, focused ion beam (FIB), laser, ultrasonic, micro electro discharge machining (EDM) etc. In the conventional micro machining methods, the problem of high cutting force arises. This process is also limited by high tool wear problems. In the other hand FIB, laser machining etc. demands high capital investment.

Because of the limitations of these technologies, non-conventional processes like Electrical discharge machining (EDM) which works on the principle of material removal by melting and vaporisation by electric discharges got a role in the fabrication of micro components. The material removal mechanism is independent of the mechanical properties of the material so that it can be used to machine very hard materials. Micro EDM has different variants which are very much flexible to the component design, and can machine the components in submicron accuracy. Micro-electrical discharge machining makes use of the principle of conventional electrical discharge machining process for the production of micro components. To handle the accuracy in to a sub-micron range the discharge energy is decreased to a very small value so that the crater dimensions will be very small and the surface finish can be controlled to 1 µm or less [1]. The process is more stochastic than the conventional EDM process because of the reduction in pulse duration to a value near to 5µs. Along with that more and more factors like viscosity of the dielectric, cavitation phenomenon during due to pressure drops, which has a negligible effect in the macro domain come to be active participant as an accuracy decision factor in micro domain. Material removal occurs by melting and vaporisation of workpiece material because of the heat energy from the electrical discharges in the presence of a dielectric fluid. The main machining parameters are controlled spark gap, voltage, current, frequency.

The important characteristics of Micro EDM compared to other micro machining processes are [2]

- There is no contact force in EDM which makes the fixtures simple in design.
- All surfaces of the tool electrode can be used for material removal.
- All materials which are electrically conductive can be machined.
- Because of the low discharge energy, material removal rate seemed to be very low in micro EDM, but the surface roughness can be reduced to R_z =1 μm or less.
- Small spark gap in the process makes the product dimensionally accurate.
- The tool and workpiece movements have to be precise to control the dimensions to a micron range.
- Precise tool dimensions and tool wear compensation strategies are very important in Micro EDM.

2. GENERAL VARIANTS AND APPLICATION OF MICRO EDM

Because of the limitations of the manufacturing processes mentioned earlier, the importance of micro EDM increased in the micro manufacturing regime. In the mass production of micro components, which can be achieved by injection moulding process, the production of micro cavities or dies with complex structures became inevitable. For the fabrication of these 3D structures with very complex geometry micro EDM is one of the solution which is capable of precise machining of any conducting materials in a comparatively economic manner [3].

- Die sinking Micro EDM: Micro injection moulding, hot embossing, micro components in medical instruments, replication molds.
- Micro Wire EDM: Micro mechanical devices for micro stamping tools, fabrication of arrays of micro electrodes and holes, arrays of micro features, high aspect ratio structures.
- Micro EDM milling: Fabrication of 3D micro moulds-cavities and dies, fine features with sharp and burr free edges.
- Dry and near dry Micro EDM: 3D micro features and slots, near mirror finish machining
- Micro EDM drilling: Fabrication of smaller and higher aspect ratio micro holes for fuel injection nozzles, spinneret holes, standard defects for testing materials, biomedical filters, starting holes for wire EDM, micro-fluidic systems.
- Micro Electro Discharge Grinding(EDG): Fabrication of conventional micro cutting and milling tools, Micro electrode fabrication, fabrication of series of pattern micro disk for micro slotting, fabrication of micro grinding tools.
- Planetary micro EDM: Blind and non-circular holes, High aspect ratio non-circular blind holes.
- Reverse micro EDM: Batch mode high aspect ratio micro electrode fabrication.

Structuring application comprises of high aspect ratio structures, fabrication of complex designs for micro molds, fabrication of 3D micro components, making hydrophobic or anti icing surfaces, fabrication of micro channels etc. Micro EDM can be used to fabricate 3D arrayed micro features with varying cross-sections which are used as tools in micro ECM process for machining cavities[4], tools for micro milling applications[5], tools for micro slitting for micro slitting applications [6].This process is also capable of machining spray holes in diesel injector nozzles [7], mechanical punches in micro forming applications [8], bio compatible micro devices [9], etc. Uhlmann et al. [10] compared the processes used for the production of micro-miniature dies using micro EDM variants.

2.1. Micro EDM milling

This is the most popular micro EDM variant in which a tool electrode with scans over the workpiece surface in a programmed manner to produce a micro component. The micro electrode used for this is fabricated by other methods like micro EDG, wire EDG, reverse EDM or lithographic processes [11].A specific CAD/CAM system is used to generate the tool path from the design of the component. One of the main limitations of the micro EDM milling is the electrode wear. It causes dimensional inaccuracies in the final product. So one of the main research areas related to micro EDM milling is the formation of reliable tool compensation methods to keep the dimensions within the tolerance limit. Some of the tool compensation methods are based on uniform wear method (UWM) [12], and some of them are applying linear compensation method (LCM) [13].The main application area is the production of 3D cavities or dies and formation of high aspect ratio structures.

EDM was applied to machine bio compatible micro devices [9] and fabricated a 25µm channel in biocompatible titanium alloy and improved the process with the assistance of ultrasonic vibration to get a reduced surface roughness around 0.4µm. Ali [14] manufactured a micro swiss-roll combustor mold cavity using the WEDG dressed tool. Optimized and verified micro ED milling process parameters were used for fabrication. The final product has the channel dimension of 0.1 mm.

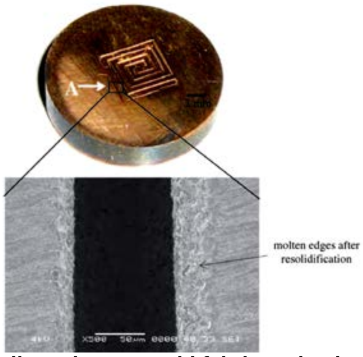


Fig. 1 Swiss roll combustor mold fabricated using Micro EDM milling [14]

Sheu and Cheng [15] fabricated micro tools and 3D micro cavities on poly crystalline diamond and concluded that RC circuits are more suitable for machining PCD tools than the transistor type pulse generators.Hung et al. [16] reported the production of micro flow channels in metallic bipolar plates used in fuel cells, using micro EDM milling. Through the use of tungsten carbide electrodes they machined channels with a depth and rib width of 500 µm, and height of 300 µm, 600 µm (aspect ratio of 0.6 and 1.2), respectively. The reaction area was in the dimension of 20 mm × 20 mm, on 50 mm × 50 mm × 1 mm SUS 316L stainless steel. Some mold inserts are made using micro EDM milling and the morphology, chemistry and structural characteristics of the surfaces are studies [17].

2.2. Die sinking Micro EDM

In die sinking micro EDM, the electrode with a negative image of the desired micro component shape is moved to the workpiece surface with a definite speed according to the material removal rate. The main hindrances in the application of die sinking micro EDM are the fabrication of complex shaped electrodes and flushing of dielectric through the small spark gap in micro EDM. One of the major applications of die sinking EDM is the fabrication of circular and non-circular holes with high aspect ratio. Tong et al. [19] machined non-circular holes on metallic surfaces with the help of micro-amplitude vibration of workpiece by a piezoelectric (PZT) actuator and observed that the machining efficiency increased 18 times and the dimensional accuracy improved by 10.5 µm. Different types of processes including lithographic process or micro milling are used to machine the electrodes for die sinking EDM [10].

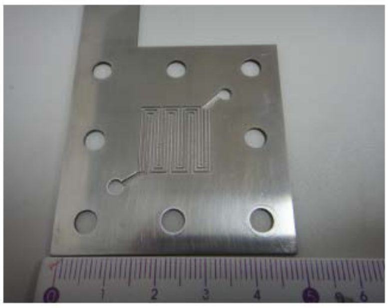


Fig. 2 Metallic bipolar plates fabricated using micro EDM milling [16]

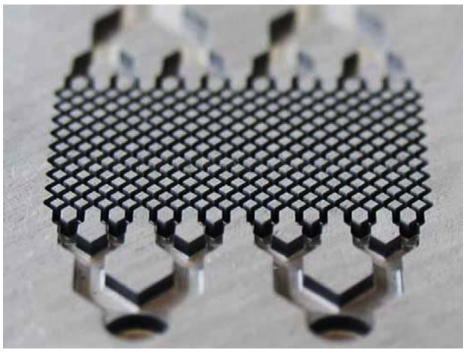


Fig. 3 Micro die sinking electrode for micro-mixing device made with miniaturized end mills [10]

2.3. Micro Wire EDM

In this variant, fine wires are used as tool electrodes in which a fresh electrode surface comes in contact with the workpiece surface each time of engagement. This will help to reduce the effects of tool wear. Micro mechanical devices and dies are manufactured using this machining method. Structures with a width of 15 mm can be reproducibly machined by micro wire with surface roughness of R_a less than 0.1 mm [10]. An array of electrodes is fabricated with wire EDM [19] and made 400 through holes on a stainless-steel plate with a thickness of 30 µm by using the modified peck-drilling methodfor batch mode hole fabrication. A dual scale super hydrophobic surface fabrication method based on WEDM is developed [20] in which a sinusoidal pattern is made on the surface followed by introducing secondary roughness in the form of micro craters is responsible for a super hydrophobic surface with a contact angle of 156º.

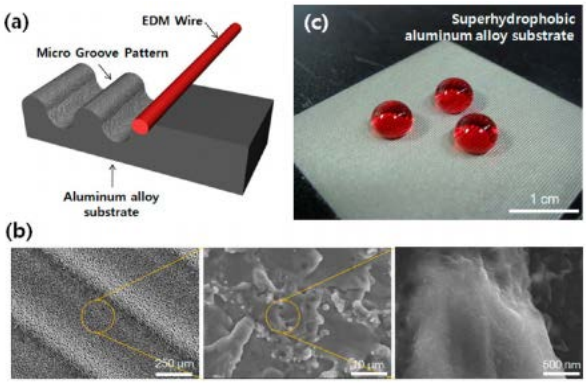
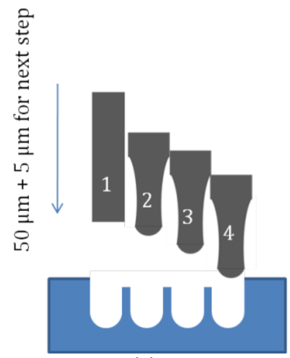


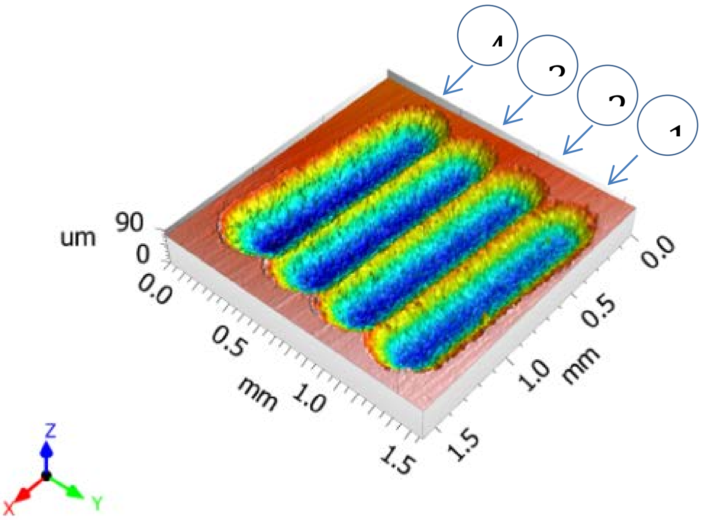
Fig. 4 (a) fabrication of dual structure on the surface by WEDM (b) SEM image of the micro craters (c) The final su hydrophobic surface [20]



(a)

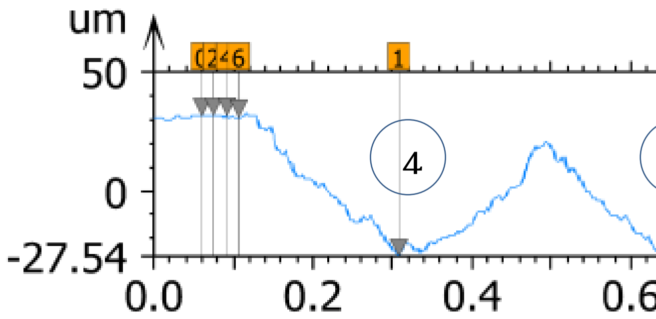
3. EXPERIMENTATION

A number of experiments in micro EDM milling done to investigate the dimensional accuracy of machining strategy. Blind Channels with 50µm de and through channels with 100µm depth machined with a tool rod of 300 µm diameter. tool material was tungsten carbide (WC) workpiece material was brass. The machine used was DT-110 Mikrotools. The space betw each channel is tried to keep around 25µm. An pulsed circuit with a peak voltage of 119 V capacitance of 100nF is used for machining. rotational speed of the spindle was 2500 rpm and feed rate was fixed to 0.2 mm/min.



(b)

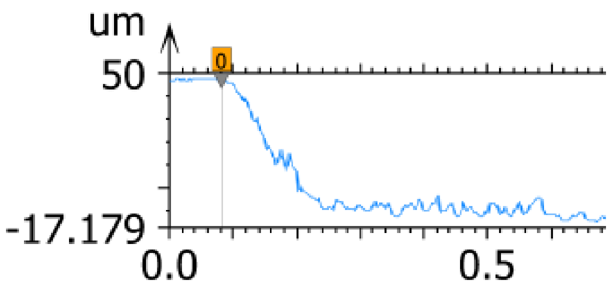
In micro milling, there is a chance of non-unifo depth and width due to the tool electrode we During the machining of blind micro channels, a compensation of 5µm is given to maintain the uniform depth of all the channels. The compensation value is approximated from the trial experiments done to investigate the tool wear rate. Image of the machined channel with the channel profile and depth measurements are taken using Taylor Hobson CCI non-contact type 3D profilometer.



Parameters	Unit	0-1
Horizontal distance	mm	0.248
Height difference	um	-59.055

(c)

Fig.5(a) shows the machining strategy. After machining each channel with a length of 1mm, tool is moved to the next position and the depth to be travelled is increased by 5 µm. This compensates the eroded length of the tool electrode approximately. Because of this compensation, the top surface of the web between the channels always experiences side sparking from a new part of the tool which is not eroded yet. So this overcut is responsible for the height difference between the top surface of the workpiece and the centre thickness of web.

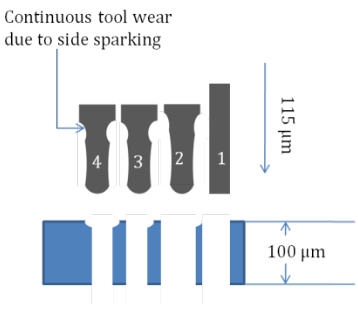


Parameters	Unit	0-1
Horizontal distance	mm	0.690
Height difference	um	-54.992

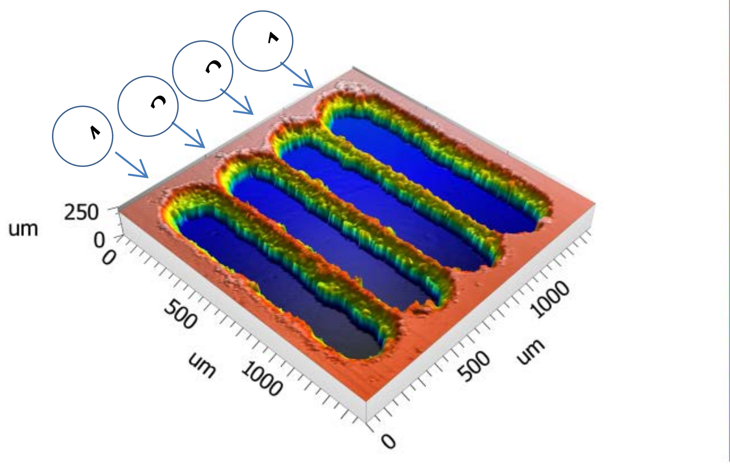
(d)

Fig. 5(a) Machining method of series of channels with 50 µm depth machined using micro EDM milling (b)3D topography of blind channels(c) channel depth measurement (d) lengthwise profile of a single channel

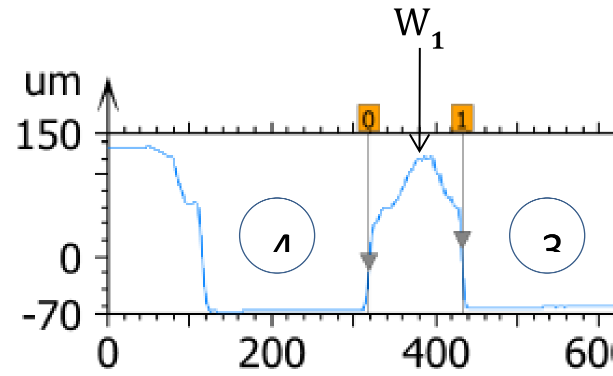
Fig. 5 (b), (c) and (d) shows 3D topography of all the channels, cross-section from the center passes throgh all the channels, and the 2D profile of a single channel along the legthwise respectively. Fig. 5 (c) shows very less differenece between the depths of each channel (1 to 4). From the Fig. 5 (d), it is clear that the channel has a uniform profile along the length direction. The variation in depth between all the channels is in the range of ± 3.4 µm.



(a)



(b)



Parameters	Unit	0-1
Horizontal distance	um	114.146
Height difference	um	26.988

(c)

Fig. 6 (a) Machining method of series of through channels using micro EDM milling (b) 3D topography of through channels (c) Measurement of web thickness

In the second experiment, through channels are machined with the same machining conditions and same tool electrode with 300 µm diameter without any type of tool compensation. The tool is moved to a depth of 115 µm in each step to ensure the through cut as shown in Fig. 6 (a). From Fig.6 (c) it is clear that the width of the channel at the top is more than the bottom. Furthermore, web thickness also varies because of the side sparking of the tool electrode.

After through hole drilling of 115 µm (Fig. 6 (a)), the tool is moved to 1mm horizontally to make the channel. Fig. 6 (b) shows the 3D topography of all the channels. This machining strategy is applied for all the through cut channels without changing the tool. So the tool surface is eroded continuously from the same location. As the machining goes on, lesser material will be available from the tool surface due to side sparking. It results in variation in the width of the channels as well as the web thickness from 1 to 4. It means width of the channel decreases in the subsequent passes (1 to 4) and the web thickness increases from W_1 to W_3 as shown in Fig. 6 (c).

From the above results, it is observed that micro machining to 100 µm range can be efficiently performed by micro EDM process.

4. SCOPE OF MICRO EDM

Micro EDM has is a manufacturing process which is capable of machining a large variety of materials and complex geometric features. The application areas can be extended to the fabrication of micro molds for lab on chip applications especially inertial micro fluidic devices which are used to sort and collect biological cells. This method can be used as a selective surface patterning tool to fabricate channels with micro pillared arrays which controls the flow velocity and mixing of fluids inside the channel. Micro EDM will be useful tool for fabrication of biocompatible stents. Improvements in the positioning accuracy and machine tool capability will help to produce tools with sub-micron dimensions.

5. CONCLUSION

In this paper, the basic features of micro EDM was discussed along with the limitations and capabilities. The application areas of the general variants of micro EDM were summarized. Each variant was discussed extensively which revealed that micro milling is capable of making complex shaped molds and cavities, die sinking EDM can produce symmetric and non-symmetric holes with high aspect ratio, wire EDM is useful in the production of fine features with very small dimensions, EDG is mostly used for the production of tools for conventional micro milling, Electro chemical machining, and the smallest electrode fabricated using micro EDM has a diameter of 2.8 µm. Some experiments are done to investigate the dimensional accuracy of the process and successfully machined series micro channels (blind and through) with a good control on the dimensions. In the blind micro channels, the variation in the depths of the micro channels is very less and the channels have a uniform profile in the direction of length. The height difference between the workpiece top surface and web top is due to side sparking of tool electrode. In the through micro channels, there is variation in thickness of the web as well as the channel width because of tool wear due to side sparking.

6. REFERENCE

[1] M.P. Jahan, Y.S. Wong, M. Rahman, “A study on the fine-finish die-sinking micro-EDM of tungsten carbide using different electrode materials”, Journal of Materials Processing Technology (2009) 3956–3967

[2] J. Fleischer . J. Kotschenreuther, "The manufacturing of micro molds by conventional and energy-assisted processes", Int J AdvManufTechnol (2007) 33: 75–85.

[3] M.P. Jahan, Y.S. Wong, M. Rahman, “Micro-Electrical Discharge Machining (Micro-EDM): Processes,Varieties, and Applications”, Elsevier Ltd. (2014)

[4] Kim, B. H., Park, B. J, Chu, C. N,“Fabrication of Multiple Electrodes by Reverse EDM and Their Application inMicro ECM”, J. Micromech. Microeng. 2006, 16 (4), 843–850.

[5] J. Fleischer, "New applications for micro-EDM", J. Micromech. Microeng. 16 (2006) 843–850

[6] Chia-Lung Kuo, Jing-Dae Huang , , "Fabrication of series-pattern micro-disk electrode and its application in machining micro-slit of less than 10 µm", International Journal of Machine Tools and Manufacture 44 (2004) 545–553

[7] Tong Hao et al., "Mechanism design and process control of micro EDM for drilling spray holes of diesel injector nozzles", Precision Engineering 37 (2013) 213– 221

[8] HS Liu, BH Yan, FY Huang, KH Qiu,“A study on the characterization of high nickel alloy micro-holes using micro-EDM and their applications”, Journal of Materials Processing Technology 169 (2005) 418–426

[9] M Murali and S H Yeo, "Bio combatible micro devices by micro EDM", Biomedical miceodevices 6:1, 41-45, 2004

[10] EckartUhlmann, SaschaPiltz, Ulrich Doll, "Machining of micro/miniature dies and moulds by electrical discharge machining—Recent development", Journal of Materials Processing Technology 167 (2005) 488–493

[11] H.S. Lim et al. , "A study on the machining of high-aspect ratio micro-structures using micro-EDM",Journal of Materials Processing Technology 140 (2003) 318–325

[12] ZY Yu, T Masuzawa, M Fujino, “Micro-EDM for three-dimensional cavitiesdevelopment of uniform wear method” CIRP Annals-Manufacturing Technology, 1998

[13] JayakumarNarasimhan, Zuyuan Yu, and Kamlakar P. Rajurkar, “2005-Tool Wear Compensation and Path Generation in Micro and Macro EDM”, Journal of Manufacturing Processesystems(2005)

[14] Mohammad Yeakub Ali, "Fabrication Of Microfluidic Channel Using Micro End Milling AndMicro Electrical Discharge Milling", International Journal of Mechanical and Materials Engineering (IJMME), Vol. 4 (2009), No. 1, 93 -97

[15] Dong-Yea Sheu and Chung-Chieh Cheng, "Micro Three-Dimensional Cavities Tools Fabrication on PCD by µ-EDM Scanning Process", Materials and Manufacturing Processes, 28: 42–47, 2013

[16] Jung-Chung Hung, Tzu-Chun Yang, Kuo-chou Li, "Studies on the fabrication of metallic bipolar plates—Using micro electrical discharge machining milling", Journal of Power Sources 196 (2011) 2070–2074

[17] D. M. Cao, J. Jiang, W. J. Meng, J. C. Jiang, W. Wang, "Fabrication of high-aspect-ratio microscale Ta mold inserts with micro electrical discharge machining", MicrosystTechnol (2007) 13: 503–510

[18] Hao Tong, Yong Li, Yang Wanga,“Experimental research on vibration assisted EDM of micro-structures with non-circular cross-section”, journal of materials processing technology 2 0 8 (2 0 0 8) 289–298

[19] Shun-Tong, "Fabrication of high-density micro holes by upward batch micro EDM", J. Micromech. Microeng. 18 (2008)

[20] Won GyuBae, Ki Young Song, YudiRahmawan, Chong Nam Chu, DookonKim,Do Kwan Chung, Kahp Y. Suh, "One-step process for superhydrophobic metallic surfaces by wire electrical discharge machining", ACS Appl. Mater. Interfaces 2012, 4, 3685−3691