

# Recent status of Spark Assisted Chemical Engraving: A Review

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## ABSTRACT

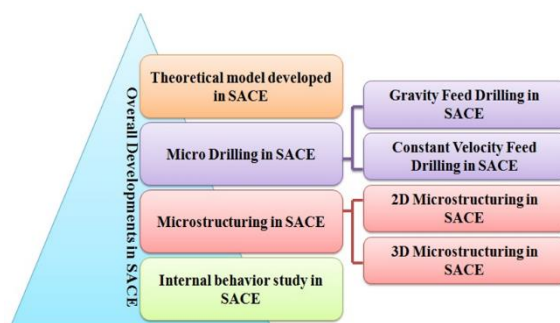
The Electrochemical Discharge Machining (ECDM) is an advance technology; it has ability to machine some electrical nonconductive materials such as ceramics and glass. The Spark Assisted Chemical Engraving (SACE) technology is based on ECDM phenomenon. SACE is a process of glass machining by using electrochemical discharges, it gives smooth surface and high aspect ratio. The Spark Assisted Chemical Engraving has a broad range of applications in the field of MEMS interfacing, micro fluidic devices and microfactories. In this paper overall developments of SACE are reviewed up to present date with special reference to the electrochemical trends.

**KEY WORDS:** ECDM, SACE, Microstructuring, Microdrilling.

## 1. INTRODUCTION

The spark assisted chemical engraving is a phenomenon, which gives some new findings about fundamental understanding and practical implementation for process of non-conducting materials machining. From past research, it is observed that, the Material removal rates are dependent on a large number of parameters like material to be machined, used electrolyte, applied voltage and temperature (Wuthrich, 2005). The Spark assisted chemical engraving (SACE) can be utilized in applications of microfactory. According to researchers SACE is an interesting technology for microfactories due to its specific properties such as its simplicity also; it does not require more space, clean environment and heavy machining (Wuthrich, 2005). The present status of Spark assisted chemical engraving has a wide range of applications to the micromachining and this process includes a variety of materials such as copper, molybdenum, glass, quartz, tungsten, and silicon etc. By creating appropriate experimental setup, tool material assortment, power supply selection and automated 5-DOF machine, they are successfully able to achieve the micro-level machining, deposition, and surface modification (Kulkarni, 2011). In this process research is based on theoretical model, process design, machine design (Pawar, 2015). The scanning electron microscope equipment shows key role in SACE process (Pawar, 2015).

The figure.1, shows, the research developments in Spark Assisted Chemical Engraving which is classified into Theoretical model developed in SACE, Micro-drilling in SACE, Microstructuring in SACE and Internal Behavior Study in SACE.



**Figure.1. Overall developments in Spark Assisted Chemical Engraving (SACE)**

**Theoretical Model Developed in SACE:** Fascio (2003), has been studying SACE by using an electrochemical view. From the results they have prepared two theoretical models, the first model is based on percolation theory and contains parameters like current and voltage while the second model is based on sparks characteristics i.e. Duration and amplitude. The results obtained from experiments explain the discharge activity. The paper has revealed that the SACE research has released a new approach towards the significant phenomenon in electrochemistry i.e. Activity loss of coated anodes and electrode effects. Jalali (2009), developed a quantitative model in relation to the drilling evolution taking into account the occurrence of the discharge regime, transition step and hydrodynamic regime.

**Micro Drilling in SACE:** Gautam (1997), experimentally investigated electrochemical spark drilling (ECSD) process with the help of different tool kinematics. The ECSD with rotating tool shows successful improvement for electrically non conducting ceramics machining i.e. borosilicate glass and quartz as well as the improvement in process performance has been shown by tool rotation. They concluded that, by using ECSD process the good circularity and smooth cuts are possible in quartz and borosilicate glass. Jiang (2014), done a comparative study between conventional ECDM and hybrid ECDM incorporating mechanical drilling, where drilling was done with glass material. The Material removal mechanism for both conventional and micro drilling incorporated ECDM was investigated by experimentation and FEA simulation. The machining speed for micro-drilling incorporated ECDM was notably improved in comparison with conventional come within reach of at least 62%. Gao (2014), used  $\varnothing 200\mu\text{m}$

tungsten carbide drill to make micro holes in Pyrex Glass by SACE process. From an outcome, it is observed that machining time, drill rotation direction, rate and the contact force affected the processing performance noticeably. The author successfully obtained aspect ratio of about 8.8.

**Gravity Feed Drilling in SACE:** Wuthrich (2006), proposed a systematic characterization method of Gravity-feed drilling method which is mostly used for glass micro-hole drilling with the help of spark assisted chemical engraving (SACE). They also studied voltage influence, tool shape and force. From the results they found that, the SACE gravity-feed drilling gives two regime named as discharge regime having drilling speed 200–250 $\mu\text{m}$  and hydrodynamic regime having drilling speed up to 300 $\mu\text{m}$ , these regimes are dependent on drilling depth. They also observed that the needle-shaped tools and the resistance low inter-electrode increases machining speeds. Wuthrich (2006), conducted experiments by using tool vibration technique to improve the material removal rate in spark-assisted chemical engraving (SACE). According to them the material Removal rate is an important factor for gravity-feed micro-hole drilling in SACE. From the results it is found that, the material removal rate can be improved by using sufficient tool vibration. Maillard (2007), produced micro-hole drilling in glass materials by gravity-feed with spark assisted chemical engraving which differentiated as a role of the drilling depth and machining voltage. During the experimentation they found four types of microholes, such as Well-defined cylindrical holes with smooth surface, Jagged outline holes, Holes with heat affected zone and Holes with thermal cracks. Morrison (2009), has introduced a new method of feedback controller in gravity feed drilling in glass material. The proportional controller is used for feeds back current depth into the voltage signal, which was employed to reduction of process variation. Due to this mechanism, it improved the quality of the machined holes. Mousa (2009), experimentally proposed two concepts, first drilling in the discharge regime is quicker for electrodes which is made of material with high thermal conductivity and low heat capacity as the hot electrode supports the discharge activity and a second drilling in the hydrodynamic regime is slower for electrodes made up of material with high thermal conductivity, as the temperature of the machining zone is lesser consequential in higher viscosity of the molten work piece. Jalali (2009), suggested that, the material removal mechanism is a combination of local work piece heating followed by chemical etching.

Ozhikandathil (2011), explored the opportunity of using an electrically conductive material as an etch-stop layer for SACE gravity-feed drilling. Micro holes in 35 $\mu\text{m}$  thick silica layers on a silicon substrate were prepared with constant DC and pulsed DC machining voltage. They found two observations during this machining process, first for bulk silicon, machining stops due to inhibition of electrical discharge movement around the tool electrode owing to its contact with the conducting substrate and second for buried silicon, machining stops as the silicon acts as a prolongation of the tool-electrode on which a gas film is formed protecting it from further etching. Abou Ziki (2012), measured the thermal expansion and the tool wear for tungsten, steel and stainless steel electrodes during SACE machining experiments. Stainless steel electrode was established to have the highest expansion among the three electrodes with almost zero tool wear, while tungsten has the highest tool wear. A simplified lumped thermal model for tool expansion and its dynamics similar match with observed values. The concluded result shows the highest measurement accuracy and more correct micro-machining by SACE.

**Constant velocity Feed Drilling in SACE:** Abou Ziki (2013), experimented the forces which are exerted on the tool-electrode during the process of constant-feed glass micro-drilling by using the spark assisted chemical engraving (SACE). For this experiment the authors use different machining tool feed rates, voltages and tool sizes For different voltages and tool sizes a figure of the force regions in the hole-depth vs. tool feed-rate plane is presented. They found two steps of micro drilling i.e. In low depth the work-piece surface heating is a rate limiting step while electrolyte flushing for high depths. The obtained results, tolerate the current signal usage for identifying the relation between the glass surface and the tool. Didar (2008), studied characterization and modelling of 2D-glass micro-machining with constant velocity by using spark-assisted chemical engraving. The model which is proposed for 2D-glass micro-machining using SACE technology is very applicable to microfluidic and lab-on-chip devices.

**Microstructuring in SACE:** Microstructuring technique is a sophisticated process in SACE, which can be form 2D and 3D structure by moving the tool from the work sample.

**2D Microstructuring in SACE:** Didar (2008), studied characterization and modelling of 2D-glass micro-machining with constant velocity by using spark-assisted chemical engraving. They signifies the parameters which are affecting the quality and geometry of this technology machined microchannels. According to them there are five types of microchannels such as well-defined linear micro-channel edges and a smooth channel surface, jagged outline contours with a smooth micro-channel surface, heat-affected edges with a smooth micro-channel surface, heat-affected edges with an unsmooth micro-channel, surface and thermal cracks and deteriorated micro-channels. Didar (2008), used this technology to developed 2D-micro-machining with a micro-channel pattern was done on the soda lime glass. The authors experimentally observed difference in hardness of the machined areas which shows that the material becomes softer after machining and due to this the change in glass density is observed. Also, nano-indentation test shows that the density of the machined surface decreases during the machining process. Finally, they concluded that the change of density is endorsed to the fast cooling of the work piece during the machining process.

Abou Ziki (2012), created successfully surface textures from feathery to porous, spongy textures on glass surface using SACE technology. The experimental results show that the electrolyte viscosity is found to be the most significant parameters influencing the channel texture other than the parameters of tool workpiece gap, machining voltage and tool travel speed.

**3D Microstructuring in SACE:** Fascio (2003), has studied this process by an electrochemical view. From the observed results two theoretical models are prepared first model is based on percolation theory while the second model is based on sparks characteristics. The percolation theory contains parameters like current and voltage and in spark characteristics, duration and amplitude are used as parameters.

**Internal Behavior Study in SACE:** Fascio (2003), discovered current and voltage measurements in spark assisted chemical engraving joining photographs and potential sweep. The observation shows the low potentials a cone shaped area enclosing finely dispersed hydrogen gas is produced around the tool cathode and at high potentials there are strong current variation mostly due to bubble coalescence. From this they concluded that the discharge activity has been done through a potential perturbation method. Wuthrich (2005), studied physical principles along with the miniaturization of spark assisted chemical engraving. They found that the electrolyte surface tension affects the thickness of gas film and thus the characteristics of current voltage have been established. The electrode wettability and Surface tension are mainly dependent on the concentration of electrolyte and they can also influence by adding surfactants i.e. liquid soap. The results obtained from present investigation shows potential for the advance characterization of SACE process. Wuthrich (2005), gives applications of gas film in spark assisted chemical engraving for micro-machining. This process have a limiting factor i.e. the unstable gas film, which is present around the tool electrode and used to carry the necessary electrical discharges which is required for machining. According to the authors it is verified that, the decrease in thickness of gas film due to wettability changing of tool electrode is significantly resulted in to higher machining repeatability. Wuthrich (2006), stated that SACE is a complex machining process. In this process, there are so many sub processes are involved and the results obtained from this is indirectly dependent on external and well defined parameters i.e. applied voltage, electrolyte concentration and composition. From the experimental set up it is concluded that there is no direct relation between current and material removal rate as well as the active process control possibility is discussed which is based on current measurement. Allagui (2009), formed a novel theoretical algorithm to find out gas film formations and subsequent discharges in the electrochemical discharge phenomenon whereas current signal was taken into considerations. This is performed by the wavelet analysis as a denoising tool amid the discrete Meyer wavelet as base function. The suggested algorithm allocates to establish experimentally the gas film life time and its essential building time prior to each series of discharges. From the experimental data, it is accomplished that the gas film is more stable at high terminal voltages whereas its creation time reduces with it.

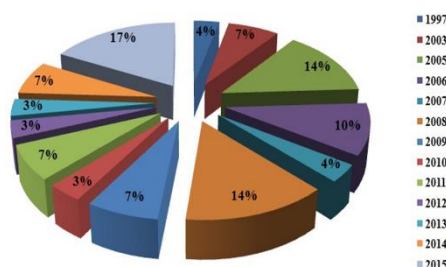
Abou Ziki (2014), invented a study of machining temperature in SACE. In this process the temperature is proficient to rise and fall depending on the drilling strategy and the machined structure geometry. They experimentally said that the local temperature depends on the machining configuration and the machined surface geometry which influence local flushing. For shallow structures, the electrolyte is aqueous where its temperature is about its vaporization temperature. Though, for deep structures, the temperature is higher and can accomplish that of the tool in case of tool-glass contact. Hence, electrolyte appears in molten form. Abou Ziki (2015), considered the scenery of the tool substrate contact forces in drilling. The experimental outcome shows that a bond is produced among the tool and the glass surface while machining. In actuality, it is established that the bond has a well-defined mechanical strength and can arise at almost zero mechanical tool-glass contact, signifying that a chemical bond is created. The bonding process is related to the one in field assisted bonding. The current findings improve the understanding about the SACE machining mechanism.

**Overall Developments in Spark Assisted Chemical Engraving (SACE):** The Table.1, shows literature survey of Spark Assisted Chemical Engraving (SACE) study since 1997 up to present date. The Fig.2, shows percent contribution of SACE research articles for their respecting years. According to the pie chart 2008 and 2015 are more contributing years for the research of this technology.

**Table.1. Summary of Spark Assisted Chemical Engraving (SACE) research articles**

Author and Year	Progressive Developments in SACE
Gautam, (1997)	Firstly introduces rotational tool with controlled feed for improving process performance.
Fascio, (2003)	Firstly introduces 3D microstructuring and development of a model which is based on percolation theory, also experimentally observed internal behavior and affecting parameters in SACE.
Wuthrich, (2005)	Overview of SACE process from past to present, Application in microfactories, Observed gas film thickness which is most important affecting factors in SACE technology.

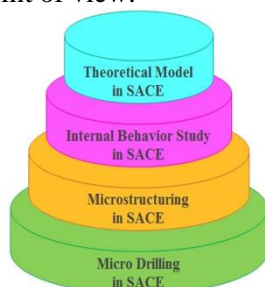
Wuthrich, (2006)	Studied an effective parameters of Gravity-feed drilling in SACE, Analysing effect of vibratory tool of Gravity-feed drilling in material removal, also stated that the current is most important parameter which affect the gas film occurring in SACE process.
Maillard, (2007)	Geometrical characterization of micro hole in Gravity-feed drilling.
Morrison, (2008)	Introducing a new method of feedback controller assisted Gravity-feed drilling, Studied thermal conductivity of tool electrode in Gravity-feed drilling, 2D Microstrucutre was done by using constant velocity, Studied the local hardness measurement of machined 2D microchannels.
Jalali, Allagui (2009)	Developed theoretical model for Gravity-feed drilling, Development of a two-step algorithm for identifying Gas film formation time and gas film life time in SACE.
Kulkarni, (2010)	ECDM used for micromachining, deposition and surface modification in various materials of copper, tungsten, molybdenum, glass, quartz, and silicon.
Ozhikandathil, Abou Ziki, (2011)	Identified new method of etch-stop layer for Gravity-feed drilling, Finding out the thermal expansion and tool wear of different tool material of Gravity-feed drilling.
Abou Ziki, (2012)	Successfully produced feathery-like to porous sponge-like surface textures using SACE.
Abou Ziki, (2013)	Studied, forces exerted on the tool of electrode constant velocity-feed drilling.
Jiang, Gao, (2014)	Invented a method of micro-drilling incorporated with ECDM drilling, Producing micro holes on Pyrex glass.
Abou Ziki, (2015)	Developed a theoretical model by considering the effect of temperature in the SACE process, Identified behavior of tool-substrate contact drilling forces in this process.



**Figure.2. Yearly percent contribution of Spark Assisted Chemical Engraving (SACE) research articles**

## 2. CONCLUSION

Spark Assisted Chemical Engraving is a new technology used to treat the electrically nonconductive materials. The present article focuses on the important trends in electrochemistry which will give new ways for further study in the field of hybrid machining processes. The fig.3, shows ascending circular pyramid diagram of SACE categories, from this it can be concluded that, the microdrilling method is widely applicable in SACE experimental studies due to its advancement and noticeable performance in drilling parameters. Whereas, the research on the basis of theoretical model is less due its complicated methodology. From the present study it is observed that, for more findings and outcomes some further work should be done on SACE technology regarding industrial applications and electrochemical point of view.



**Figure.3. Ascending circular pyramid diagram of SACE categories**

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