INFLUENCE OF GAP VOLTAGE AND TOOL MATERIAL ON MICRO GEOMETRY PRODUCED ON SILICON WAFER USING MICRO EDM

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Abstract: *In the present work, a Micro EDM (Micro Electro Discharge Machine) is developed in-house with piezoactuated adaptive tool feed mechanism and investigations on Silicon wafer machining is carried out at different machining conditions and with copper and tungsten tool materials. Kerosene is used as the dielectric medium. The influence of the tool feed mechanism on the surface roughness is investigated with different feed back gap voltages and it was found that gap feed back voltage of 23V generates better surfaces when compared to lower feed back gap voltages. The effect of sparking frequency on surface roughness is investigated and it was found that higher frequencies generate a good surface with lower surface roughness value. Side Spark Gap (SSG) is evaluated for copper and tungsten tool materials at different gap voltages and duty cycles. It was found that SSG increases with applied gap voltage. There was no much variation in SSG at different duty cycles. Copper tool material generates higher SSG compared to Tungsten tool.*
Key words: *Micromachining, micro EDM, micro geometry, side spark gap*

1. INTRODUCTION

Micro Electro Discharge Machining (Micro EDM) is a thermal erosion process where the material is removed by the action of the spark formed between the tool and workpiece which forms the electrodes with opposite polarity in an electric circuit. Micro EDM differs from the conventional EDM in that the spark energy is of two to three orders less than that of the conventional EDM.

Micro EDM is an attractive microfabrication technique for production of 3D microstructure in silicon. Micro machining of silicon wafers by EDM have been reported by several research groups (Y.F.Luo et al., 1992, Dominiek Reynaerts et al., 1997, Hideo Takino et al., 2004, 2005). A detailed insight into the prospects of electrical discharge machining technology was given (Kunieda M. et al. 2005), by interrelating recent achievements in fundamental studies on EDM with newly developed advanced application technologies. Improvement in the surface finish of the micro machined structure on silicon by Micro EDM was reported by incorporating the low energy sparks and tool rotation (Yeo. H.S., Nachiappan R. 2001). Effect of electrode jump height and the debris distribution on the wall concavity in deep drilling of holes by EDM was reported (Serkan C. et al., 2004). These works are more concentrated on the micro manufacturing, surface finish improvements by adapting different techniques. However there are no reports on Side Spark Gap (SSG) variations for different machining conditions. Further it is also necessary to study about the surface characteristics improvement with the proper feed control mechanism.

In the present study, a piezoactuated tool feed mechanism is incorporated in Micro EDM and micro machining of silicon wafer is investigated. In Section 2, an in-house developed prototype Micro EDM is described. In Section 3, influence of tool feed control and other machining parameters such as gap voltage, duty cycles, spark frequency on SSG and surface finish is experimentally investigated. Finally, the study is summarized in section 4.

2. IN-HOUSE DEVELOPED PROTOTYPE MICRO EDM

A prototype Micro EDM machine was set-up with piezoactuted adaptive tool feed mechanism. The workpiece is mounted on X-Y-θ stage to generate the linear, circular and spiral motions with respect to the tool as shown in the Fig. 1. A tool holder is used which can hold tools of diameter 10μm and above. Tool is mounted on a

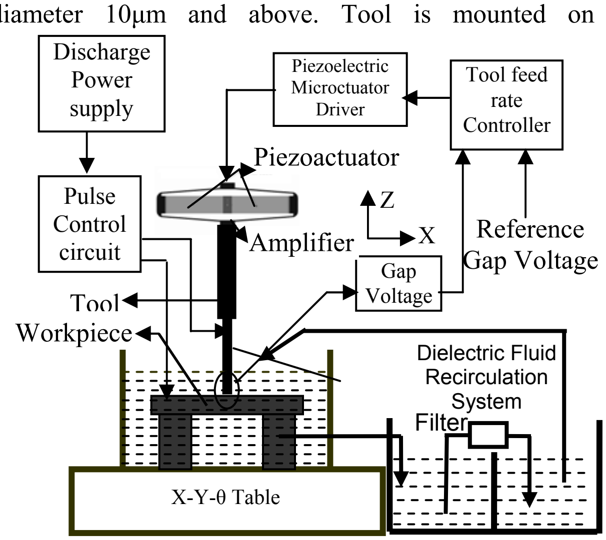

Fig. 1 Micro EDM Set-up

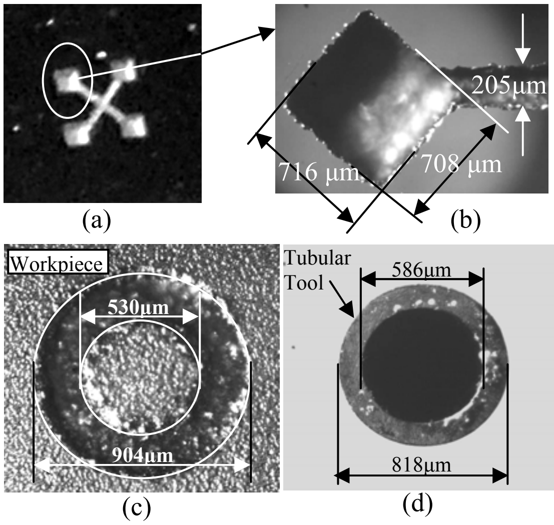

Fig. 2 (a) Cross channel with square reservoirs
(b) Magnified view of one square reservoir
(c) Circular Channel with Central Island fabrication using (d) Tubular Tool

Table 1 Parameters used for dimensional characterization of drilled hole

Input Voltage	50 ~ 90 V DC
Frequency	1~5kHz
Duty Cycle	10 to 50 %
Polarity	Workpiece (negative) and tool (positive)
Workpiece	Silicon wafer (P type, Boron doping, Resistivity : 0.1 Ω cm, Thickness: 622 µm)
Tool electrode	Tungsten wire (Diameter – 125µm, 150µm, 192µm) Copper wire (Diameter - 139 µm, 114 µm 157 µm,)
Dielectric medium	Kerosene

piezoelectric microactuator, which in turn connected to the Z-axis. A transistor type pulse generator generates a pulsed DC signal at a specified frequency and duty cycle and this signal is connected to the tool and the workpiece. Power supply circuit, pulse generation circuit and tool feed control circuit are integrated into a single control unit.

Kerosene is used as the dielectric medium to carry out micro machining experiments on Silicon wafer (P type, Boron doping, 0.1 Ωcm resistivity, 622µm thick). A vision based measurement system is developed to measure the dimensions of the micro features. National Instruments Compact Vision System (NI 1454CVS) along with the Basler CCD camera (Basler601f, 640×480pixels, each pixel measuring 9.9µm×9.9µm) is used along with a microscope with 10× objective to grab the image of the components machined by Micro EDM. National

Table 2 Analysis of Variance for Grey relational grade

Process Parameter	Contribution (%)
Voltage	50
Frequency	11
Duty Cycle	35
Error	4
Total	100

Instrument's Vision Builder software is used to calibrate the Video Microscope and to measure the dimensions of the micro features. Experiments are carried out at different gap voltage, duty cycle and reference voltage and their effect on SSG and surface roughness are analyzed. Table 1 lists the different parameters considered for micro machining.

2.1 Micro structures machined on Silicon wafer

Fig. 2 shows microstructures machined on silicon wafer (P type, Boron doping, 0.1Ωcm resistivity, 622µm thick) by using round and square shaped copper tools. Fig. 2(a) and (b) shows a microstructure with four square micro reservoirs connected by two micro channels machined on silicon wafer. Fig. 2(c) and (d) shows a blind hole with a island at the center and the tool used for machining this structure respectively. By observing these microstructures, it was found that although complex micro profiles were fabricated, their dimensions are quite different than the dimensions of the tools used for producing these microstructures. It is very important to investigate the machining parameter that causing these variations in dimensions and thereby controlling that parameter to achieve the required dimensions on the microstructure.

3. EFFECT OF VARIOUS MICRO EDM PARAMETERS

3.1 Effect of tool feed control on surface roughness

Tool feed control is achieved by comparing the gap voltage with a reference voltage and when the gap voltage is more than the reference gap voltage, the tool is moved towards the workpiece and when gap voltage is less than the reference voltage, tool is moved away from the workpiece and hence a constant gap is maintained which can sustain continuous sparks.

By observing the voltage waveform between the tool and the workpiece while machining, it was found that the minimum voltage reached was 23V. Hence to avoid arcing and short circuit, the reference voltage should be set to 23V or above. Experiments are carried out at 23V and below 23V reference voltage and its effect on the surface roughness is investigated. When the reference voltage was set less than 23V, there was a short circuit and the tool physically touches the workpiece, whereas when the reference voltage was set 23V and above, normal sparks were observed. To support this, surfaces roughness measurements of the machined surface is carried out on an optical surface profiler (Veeco, NT1000 optical surface profiler). The surface roughness value (R_a) obtained for the machined surface with reference gap voltage of less than 23V and with 23V are 5.6µm and 4.8µm respectively. This indicates that there is a considerable improvement in the surface roughness value with reference voltage of 23V.

3.2 Influence of gap voltage and duty cycle on side spark gap

In the previous work [Muralidhara et al. 2006], Grey relational analysis on the silicon wafer machining was carried out by considering Gap Voltage, Frequency, and Duty Cycle as the process parameters and Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) as the process response. Analysis of Variance (ANOVA) was performed on grey relational grades to find the contribution of different process parameters on process response. It was found that the gap voltage and the duty cycle affect the process response to a greater extent than the other process parameter as shown in Table 2. Further to investigate their effect on the SSG, experiments were carried out at different gap voltages and duty cycles. Tool electrodes of tungsten and copper material were used for these experiments. Table 1 describes the machining condition used to conduct the experiment. After the machining, the digital image of the micro hole was obtained with help of video microscope (10X objective) with CCD camera (640X480 pixels) attached to it. Image processing and dimensional measurements of the micro holes were performed with the help of National Instruments Vision Builder software. SSG is defined as the radial distance between the tool electrode and drilled blind hole on the workpiece surface. The dimensional characteristics of blind hole drilled with tungsten and copper wire on silicon wafer were compared based on SSG. The variation of SSG was plotted against applied gap voltage and duty cycle. Besides the variation of SSG with respect to process parameters, the variation with respect to tool material was also investigated.

3.3 Influence of applied voltage on side spark gap

To investigate the effect of applied gap voltage on the SSG, Tungsten and copper tools with different diameters were considered. Fig 3 shows the variations in SSG at different gap voltages using tungsten tool of diameters 125µm, 150µm, and 192µm. Fig 4 shows the variation of spark gap with respect to different applied gap voltage using copper tools of diameters 114µm, 139µm, and 157µm.

For both copper and Tungsten tool materials, as the gap voltage increases, the SSG also increases. This may be due to following reasons:

(a) As the gap voltage increases, the gap at which the dielectric breakdown occurs also increases. Hence for higher gap voltages, the SSG becomes higher.
(b) As the gap voltage increases, spark energy increases, which will result in increased molten material volume, which will result in increase SSG.
(c) The size of the debris will increase with increase in the gap voltage as it increases the spark energy, which will result in increase in molten material volume. These large sized debris will reduce the effective gap width and sparking takes place at a lower gap width.

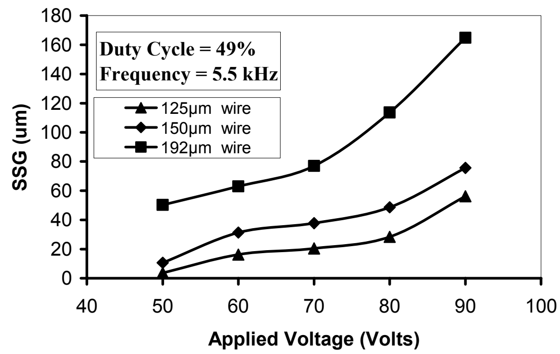

Fig. 3 Effect of applied voltage on SSG using tungsten tool

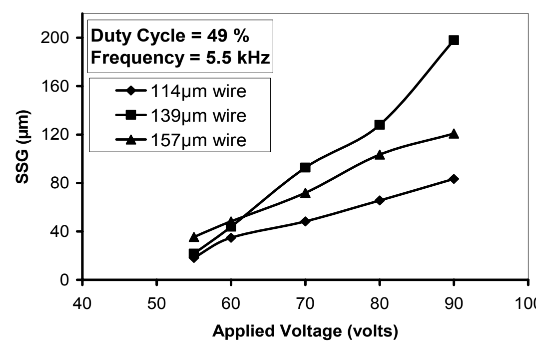

Fig 4 Effect of applied voltage on SSG using copper tool

It was observed that for copper and Tungsten tool materials, SSG increases with increase in tool diameter. This may be due to variations in the effective heat transfer rates at different tool diameters. At smaller tool diameter, the radial heat transfer due to the high temperature of the spark is less due to small radius and hence tool material erosion may takes place resulting in increase in tool wear. But at larger tool diameter, the radial heat transfer takes place more effectively resulting in reduced tool wear. This will result in higher SSG in case of large diameter tools.

Among two different tool materials, it was observed that copper tool material result in higher SSG when compared to tungsten tool. This may be due to the lower electrical resistivity (three times lower than that of tungsten) of the copper tool. Hence it may result in higher breakdown gap width and higher spark energy and hence higher SSG.

3.4 Effect of duty cycle on SSG

To study the effect of duty cycle on dimensional characteristics of blind hole, experiments are performed with tungsten and copper wire of different diameters. All the experiments are conducted under similar machining condition with applied voltage = 60V, frequency = 5.5 kHz and varying duty cycle in the range from 10% to 50%.

Fig. 5 shows the variations in the spark gap with duty cycle when machined using tungsten tool of 125μm, 150μm and 192μm diameter respectively. From above graphs it is concluded that there is no much variation of spark gap with different duty cycle. But with the increase in the tool diameter, SSG increases as it was described in Section 3.3.

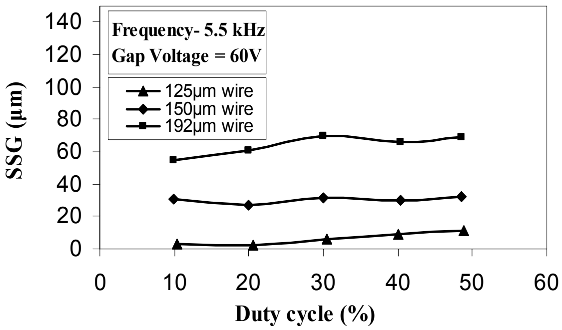

Fig. 5 Effect of duty cycle on SSG for tungsten tool

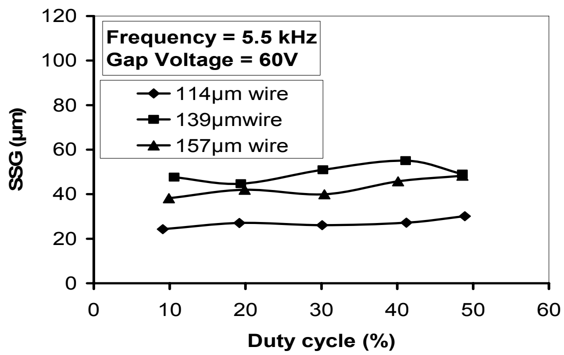

Fig. 6 Effect of duty cycle on SSG for copper tool

A similar set of experiments is conducted with copper tool with different diameter, maintaining the same machining condition as in case of tungsten wire. Fig. 6 shows the variations in the spark gap at different duty cycle using copper tool of 114μm, 139μm and 157μm diameter. In this case also similar observation is made as in the case of tungsten tool.

3.5 Influence of spark frequency on surface roughness

Straight micro channels were machined on silicon wafer by using copper foils of 55μm thickness. The effects of sparking frequency on surface roughness of the micro channels were investigated using the optical surface profiler (Veeco, NT1000). It was found that the surface roughness of the micro channels reduces with increase in frequency as illustrated in Fig. 7. This is because the energy available for material removal during a given period is shared by a larger number of sparks and hence the spark energy of individual spark was reduced which will result in reduced size of crater.

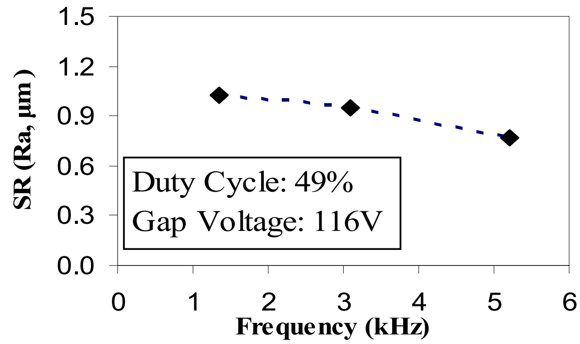

Fig. 7 Effect of frequency on SR

4. CONCLUSION

In this study, influence of various parameters on dimensional characteristics and surface roughness produced during Micro EDM of silicon wafer is investigated. To analyze the effects of gap voltage and duty cycle on micro geometry produced on silicon wafer, geometrical variations of the machined component due to the SSG at various gap voltages and duty cycles and for Tungsten and copper tool materials have been investigated. SSG was increased with increase in gap voltage. It was found that copper tool material produce larger SSG variations compared to that of the Tungsten tool material. There was increase in SSG with increase in the tool diameter in case of both the materials. Experiments were also conducted at different duty cycles and it was found that for given tool diameter, there is little variations in the SSG and hence in the size of the micro component. Experiments were carried out at different sparking frequencies and found that surface roughness decreases at higher sparking frequencies.

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