

EXPERIMENTAL INVESTIGATIONS AIMED AT THE FORMATION OF SILICON CARBIDE BY DIRECT APPLYING PULSED ELECTRICAL DISCHARGE MACHINING

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ABSTRACT: The results of experimental investigations aimed at the formation of silicon carbide by direct applying pulsed electrical discharge machining (PEDM) are presented in this paper. The purpose was to form silicon carbide (SiC) that take place at temperature more than 2000°. The methodology of experimental investigations followed by analysis of theoretical and practical research results is presented in the paper. SEM and EDX analysis of the processed surfaces by direct applying PEDM are also presented. Silicon and graphite structures of different chemical content are investigated. These structures present a synthetic composite material, both ceramic and semiconductor, which possess exceptional properties. Formed silicon carbide behaves as a very hard material, chemically inert, resistant to oxidation
KEYWORDS: silicon, graphite, carbide, electrical discharges, oxidation.

1. INTRODUCTION

Silicon carbide is an advanced ceramic material that has found widespread application both for structural and electrical purposes.

In fact, it has exclusive properties such as high hardness and strength, chemical and thermal stability, high melting point, oxidation resistance, high erosion resistance etc.

All of these qualities make SiC a perfect candidate for high power, high temperature electronic devices as well as abrasion and cutting applications. SiC is a very hard material, they improve the hardness of the composites.

Naturally silicon carbide occurs as moissanite and is found merely in very little quantities in certain types of meteorites.

The most encountered SiC material is thus man made. Today, SiC is still produced via a solid state reaction between sand (silicon dioxide) and petroleum coke (carbon) at very high temperatures in an electric arc furnace.

The formation of SiC from the reaction between silicon and carbon can take place at temperatures below the melting point of silicon.

The reduction of silica by carbon takes place through the following reaction [1]:

$$SiO_2(s) + 3C(s) \rightarrow SiC(s) + 2CO(g). \quad (1)$$

The most common forms of SiC include powders, fibers, whiskers, coatings and single crystals. There are several methods to produce SiC depending on the product form desired and its application [1-5]. Purity of the product imposes certain restrictions on the selection of the method of production.

SiC powders are produced predominantly via the traditional Acheson method where a reaction mixture of green petroleum coke and sand is heated to 2500°C using two large graphite electrodes [1].

In this paper is showed our results of obtaining silicon carbide, using plasma of electric discharges in impulse (EDI).

2. THEORETICAL PREMISES AND METHODOLOGY OF EXPERIMENTAL INVESTIGATIONS

It is important to underline that the experimental investigations were performed in the normal pressure conditions at the indoor temperature. For the realization of the experimental investigations concerning the processing of semiconductor surfaces by applying the EDI plasma a special equipment was used: the electrical block-scheme of which is shown in figure 1 [3].

The equipment consisted of the following main parts [3]: the block of power pulses which is a generator of RC-type pulses (G), the block of inducing (BI) and the block of command (BC).

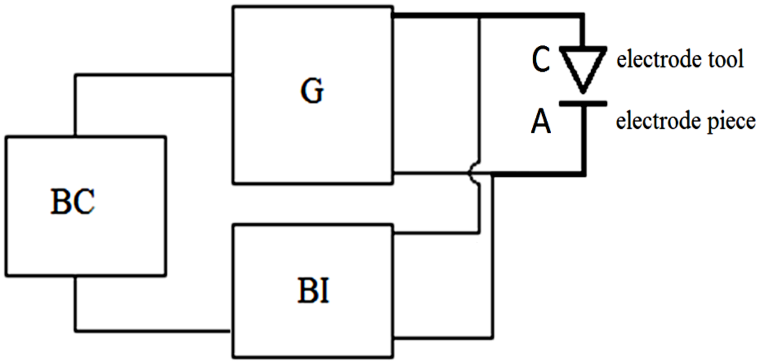


Figure 1. The main electrical block-scheme of the equipment [3]:
BC – block of command; G – RC-type pulse generator; BI – block of inducing

The command unit allows fine adjustment of the pulse repletion frequency within 1-30 Hz.

The principle of the generator operation is based on the accumulation of a certain amount of the electrical energy in the capacitor battery and its discharging into the gap in a short-time impulse (τ=220 μs).

At the moment of piercing the interstice the electrons drawn from the cathode surface turn towards of the anode.

The electrons are accelerated in the interstice electric field, they collide with gas molecules and atoms in the interstice and produce the ionization of the working medium. The dissociation and recombination of the interstice medium take simultaneously.

Under the influence of the starting impulse a conductivity channel is formed through which, due to the application of the power impulse, the force discharge takes place accompanied by the formation of plasma channel that causes significant chemicals changes in the sample surface, concerning the behavior of surface formed by graphite deposition influenced by EDI.

In order to achieve the proper energetic balance necessary for the formation of the oxidized layer caused by interaction of plasma channel with the sample surface it is to follow certain conditions: the energy density of the processed surface must be less high specific heat fusion of the sample material [3]:

$$Q=\frac{4W_s}{\pi d_c^2 S} \approx Q_{melt}, \qquad (2)$$

where Q is the heat emitted on the surface of electrodes per volume unit, J/m^3 (is energy, released

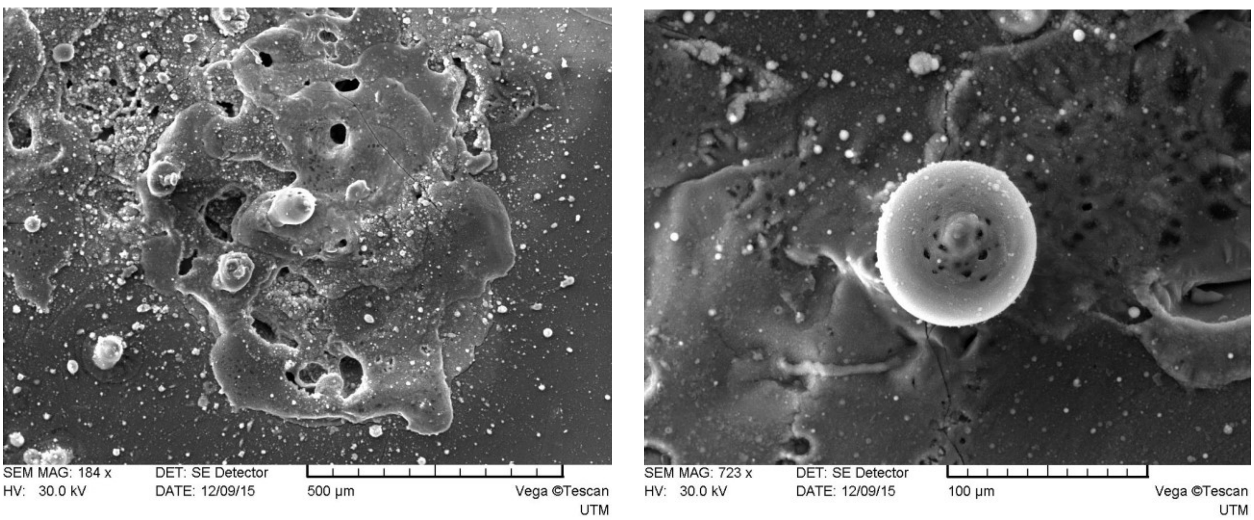


Figure 2. Sample surface (sample - anode) after processing EDI with graphite electrode:
C = 200 μF, f = 5 Hz: a) S = 1 mm, U = 100 V

in the gap); d_c is the diameter of the plasma canal, m; S is the distance between the electrodes (the interstice), *m*; $Q_{melt}= q_{melt}{\cdot}\rho_{melt}$ is the volumetric melting heat of the processed piece, J/m^3; q_{melt} is the specific melting heat of the processed piece, *J/kg*; ρ_{melt} is the material density at the temperature of melting, *kg/m^3*.

The energy released in the interstice is one accumulated in the capacitor bank of the generator, taking into account η – its degree of efficiency in the interstice [3]:

$$W=\frac{CU^2}{2}\eta, \qquad (3)$$

where C is the capacitance, *F*; and U is the voltage on the battery of condensers generator of impulses, *V*.

The heat generation rate q is given by [3]:

$$q = JE, \qquad (4)$$

where J and E are current density and electric field respectively.

3. THE RESULTS OF EXPERIMENTAL INVESTIGATIONS AND THEIR ANALYSIS

A range of experimental investigations were carried out using various dimensions of the interstice and charging voltage of the generator of RC-type impulses, that is varying the energy of the electric discharges in impulse (fig. 2).

After processing, there are to observe erosion craters after the PEDM processing of the sample, connected into the circuit of the RC-type pulse generator, in the

Table 1. Chemical composition of silicon piece surface determined by SEM and EDX analyses

Element	Weight%	Atomic%
C K	53.25	71.73
O K	3.07	3.10
Si K	43.68	25.17
Totals	100.00	

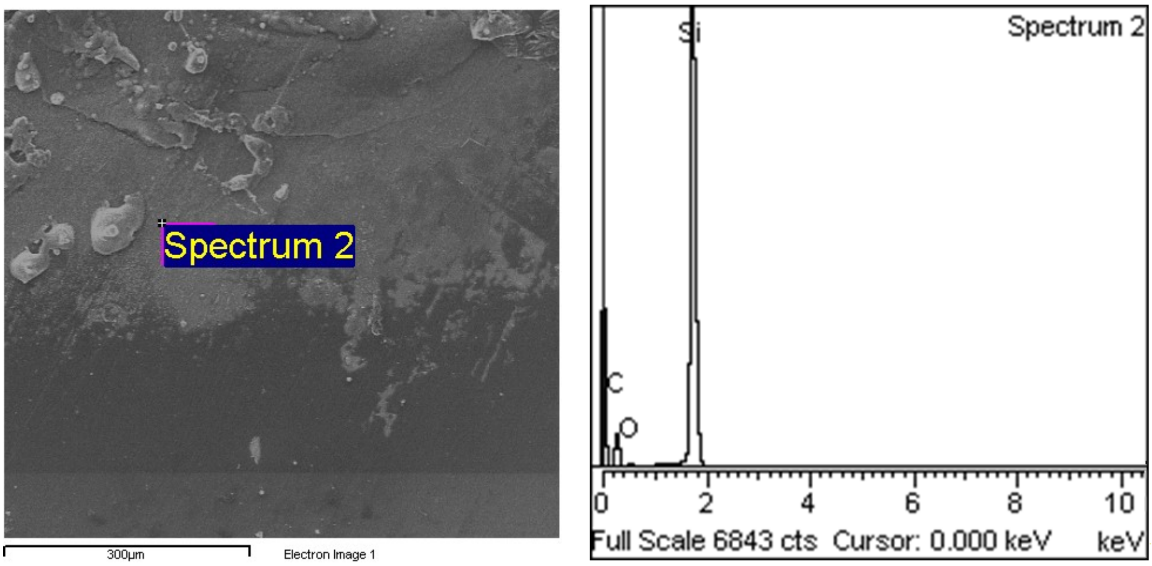


Figure 3. Morphology and chemical composition of silicon piece surface by SEM and EDX analyses

capacity of anode.

This fact attests that the appliance of the inductive impulses leads to the electrical breakdown of the semiconductor and results in the loss of the semiconductor properties.

This effect occurs due to the excessive heating of the processed surface accompanied by melting, partial vaporization and uncontrolled solidification (in amorphous state) of the processed semiconductor.

PEDM was used with the aim of SiC structures formation. This method is not too controlled, but allows getting SiC formations on the surface of silicon workpiece.

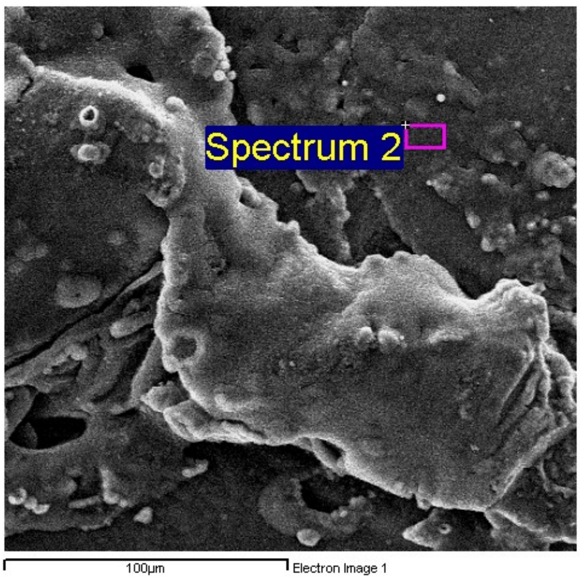
This is due to the fact that the tool-electrode is made of graphite and is connected in the discharge circuit as cathode (direct connection). This connection of the graphite tool-electrode was used because in this case it erodes more intensive as a result of the action of electrical and heat fields and cathode spraying [5]. It was observed that the graphite particles of the tool-electrode component are moved to the workpiece surface made of Si, connected in the discharge circuit as anode.

The energy of PEDM at the certain values of input circuit parameters is enough to produce melting or to create states close to melting of electrodes material, then the binding of the eroded from the graphite tool-electrode carbon in the form of particles, vapors and atoms with Si workpiece surface is followed in a short time (hundreds of μs), thus SiC formations are synthesized on the workpiece surface.

By SEM and EDX analyses of the processed by PEDM workpiece surfaces we observed that the carbon weight quantity on the workpiece surface varied in the certain points in the limits of 50-70%,

Table 2. Analyses of SiC formations

Element	Weight%	Atomic%
C K	70.92	84.59
O K	1.51	1.35
Si K	27.57	14.06
Totals	100.00	



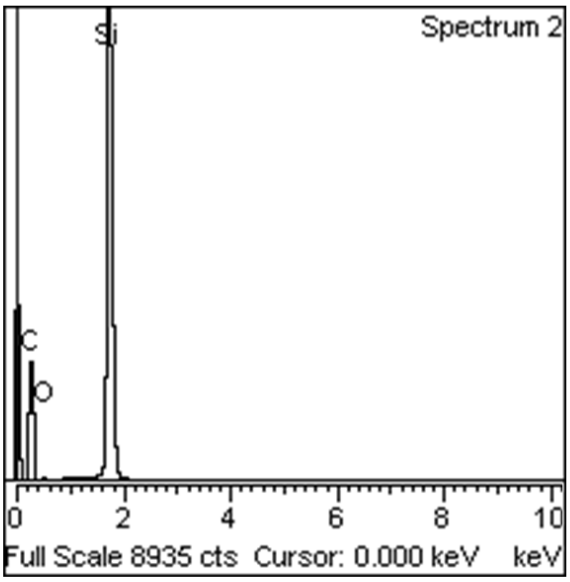


Figure 4. SEM and EDX analyses of SiC formations

and its atomic quantity varied in the limits of 70-85% (see fig. 3 and fig. 4).

The carbon cannot be completely dissolved in the base material of Si surface that is why its crystallization structures can be attested on the processed surfaces.

The appearance of the oxygen in the processed surface strata (fig. 3 and fig. 4, table 1 and table 2) can be explained by the fact that the experiences arose in the air media, in ordinary conditions of pressure and temperature, and its quantity varied in small limits of 1-3%. The small quantity of the oxygen is explained by its reduction as a result of CO and CO_2 formation.

To affirm with certitude what quantity of SiC is formed, as well as which carbon phases are synthesized on the Si workpiece surface processed by PEDM with graphite tool-electrode it is necessary to perform phase analyses (XPS, RAMAN).

4. CONCLUSIONS

- SiC formations can be synthesized on the Si workpiece surface processed by PEDM in ordinary conditions with graphite tool-electrode;
- the morphology of the obtained structures depend on the energetic conditions of processing and on the base material of the electrodes;
- formed SiC structures can be applied as primary material for abrasive tools with special destinations.

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