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Investigation of the Effect of the Discharge Channel Orientation on the Destruction Efficiency of Electronic Printed Circuit Boards

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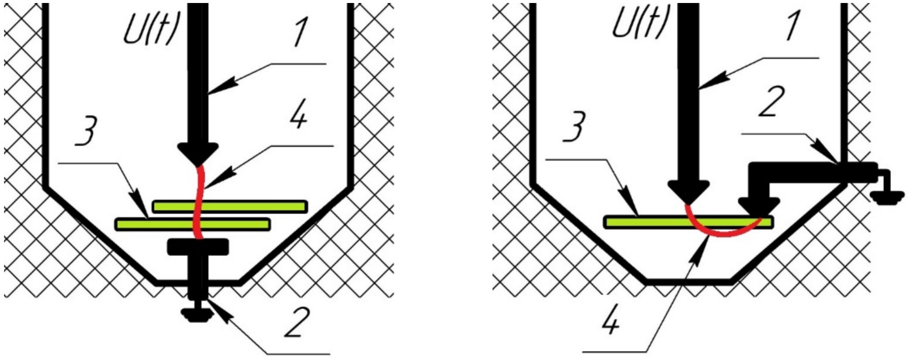
Abstract

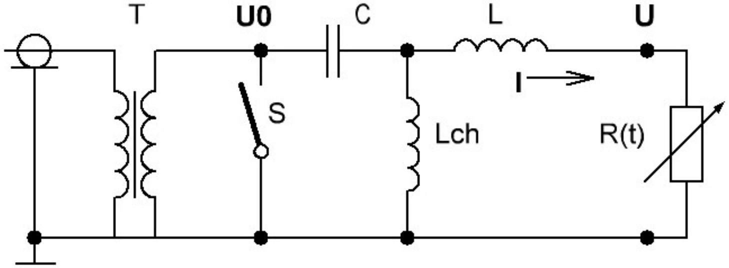
This paper presents the results of crushing of electronic printed circuit boards (PCB) through high-voltage pulsed discharges to millimeter-sized fractions suitable for subsequent separation of metal from the dielectric. Crushing was performed by a high-voltage pulse-periodic generator with an output voltage level up to 230 kV and stored energy up to 200 J. Two configurations of an electrode system with a sharply inhomogeneous electric field were studied. Main difference is orientation of the discharge channel across or along the PCB plane. Changing the orientation of the discharge channel leads to change the prevailing type of deformation and, consequently, change the crushing efficiency. Experimental results show a twofold increase of the productivity of the crushing process when changing the orientation of the discharge channel from across to along. Also the efficiency of converting stored energy into mechanical work is increase in twice. This leads to a change in the fractional distribution of crushing products.

Experimental setup

The crush chamber was filled with tap water without additional treatment with a resistivity of ~10^4 Ohms·cm. We used the PCB samples based on fiberglass FR-4, which is the most used material for the PCB.



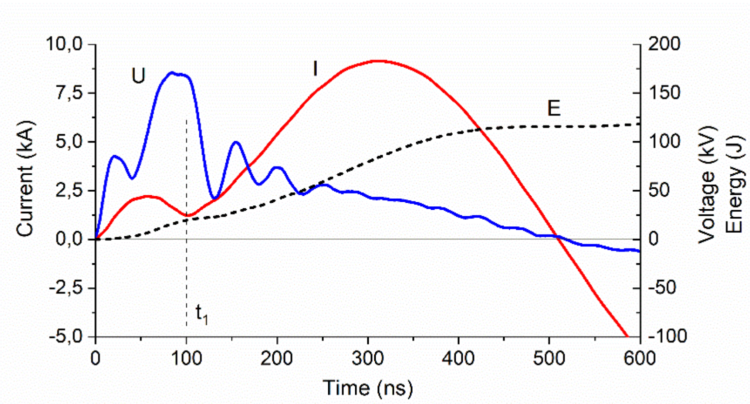
Variants of the discharge channel orientation relative to the PCB plane: a) across the PCB plane; b) along the PCB plane. 1 - high-voltage electrode; 2-grounded electrode; 3-PCB; 4-discharge channel.



Equivalent circuit: *T* – pulse step-up transformer, *C* – the storage capacitance, U_0 – charging voltage, L_{ch} – charging inductance, *L* – inductance of discharge circuit, *R*(*t*) – load, *S* – switch.

Parameters of the discharge circuit of the generator

C, nF	U_0, kV	E_0, J	L, μH	$(L/C)^{1/2}$, Ω	$(L \cdot C)^{1/2}$, ns
8	230	210	2.3	17	100



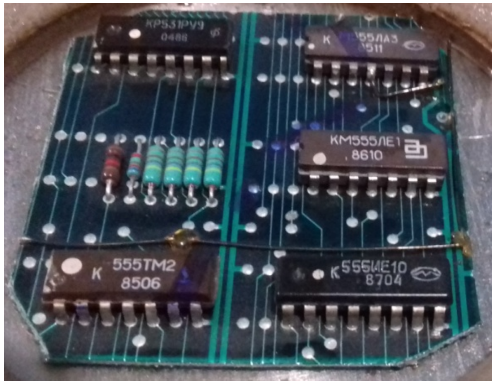
Typical waveforms of current in the chamber (*I*), chamber voltage (*U*), and energy released in the chamber (*E*).

The gap breakdown in the crush chamber occurs at a time t_1 ~100 ns. Until the moment of breakdown, the water conductivity in the chamber leads to current flow of ~2 kA and the energy is dissipated ~16 J. The average rate of voltage rise at the pulse front is ~2.5 kV/ns. After the breakdown, the discharge of the capacitive storage occurs in an oscillating mode with a half-period of ~400 ns. The amplitude of the discharge current is ~9 kA. The channel dissipates energy of ~100 J with a peak power of 420 MW during the first half-period.

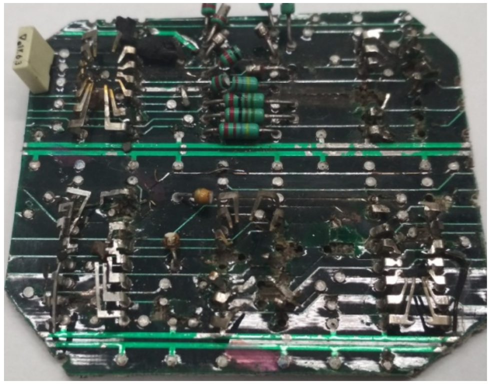
Procedure

The number of pulses per crushing cycle varied from 200 to 2000, depending on orientation of the discharge channel and the type of the PCB (2- or 4-layer). After processing, the crushing product was sequentially sifted through a set of metal meshes and divided into fractions of size: +2-5 mm, +1-2 mm, +0.5-1 mm, +0.3-0.5 mm, and +0.1-0.3 mm. The fractions were dried and weighed with an accuracy of 0.02 g, the total mass of the extracted material and the fractional distribution of the crushing products were determined. Specific characteristics were calculated: 1) the productivity of the crushing process, as the mass loss of the sample to one pulse $m^{/}$ [g/pulse], 2) the specific energy consumption of the process, as the stored energy necessary for crushing 1 g of printed circuit boards $w^{/}$ [kJ/g].

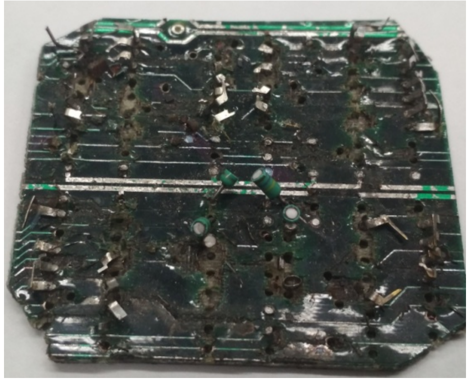
Removal of mounted elements by high voltage pulse method



Before



After 100 pulses



After 250 pulses

Removal of mounted elements by high voltage pulse method is a simple and non-energy-consuming process. For this purpose, the same electrode system can be used as when crushing the PCB itself. But in this work, the samples were cleared of mounted elements before the crushing since we were interested in the fractional composition of the products of crushing only the PCB.

Efficiency of the crushing process

The number of conductive layers significantly affects the mechanical properties of the PCB and the energy consumption for their crushing. For the PCB with two copper layers, the parameter $m^/$ is ~2 times higher and the parameter $w^/$ is ~2 times lower under identical crushing conditions. Therefore, we show the results only for the 4-layer PCB as the worst case.

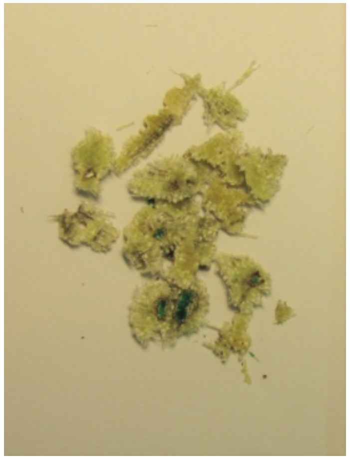
Energy consumption for crushing the 4-layer PCB

Orientation of the channel	Stored energy, J	$m^/$, mg/pulse	$w^/$, kJ/g
Across	210	1.9	109
Along	210	4.2	50

The ultimate strength of materials depends on the prevailing type of deformation. The tensile, bending and chipping strength is an order of magnitude lower than the compressive strength. Changing the orientation of the discharge channel relative the PCB plane leads to change the prevailing type of deformation and, consequently, change the crushing efficiency. Data show that with the longitudinal propagation of the discharge channel, the crushing efficiency of the PCB increases by ~2 times.

Fraction distribution

The quality of the crushing product is determined by the fractional composition and degree of separation of the components.

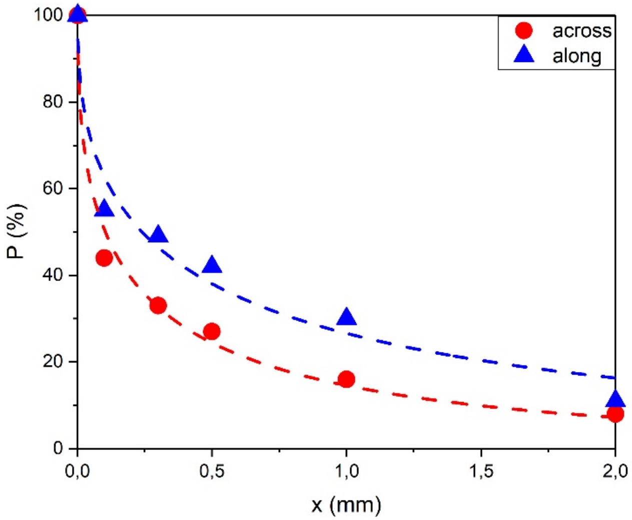

+5 мм


+2.5-5.0 мм


+0.5-2.5 мм


0.5 мм

The study of the separation degree of metal from the dielectric has shown that with electric pulse crushing it is more than 96 % in fractions of +1-2 mm, and even in fairly large fractions of +2-5 mm it is realized at the level of 70 to 90 %.



Integral fractional composition of crushing products for across and along configurations. Dash line - approximation by Rosin-Rammler law

The Rosin-Rammler law of the integral probability distribution :

$$\boldsymbol{P}(\boldsymbol{x}) = \mathbf{100} \cdot \mathbf{exp}\left[-\left(\frac{\boldsymbol{x}}{\boldsymbol{x_0}}\right)^{\boldsymbol{n}}\right],$$

where n is the coefficient that characterizes the uniformity of the material crushing (the degree of polydispersity), x_0 is the characteristic size of the fraction greater than 37% of the total mass of the destruction products.

The values of the average fraction size:

$$<\boldsymbol{x}>= \boldsymbol{x_0} \cdot \Gamma\left(\mathbf{1} + \frac{\mathbf{1}}{\boldsymbol{n}}\right).$$

Numerical parameters of the Rosin-Rammler distribution for dash lines in Fig. and average fraction size

Orientation of the channel	n	x_0, mm	R^2	<x>, mm
Across	0.45	0.23	0.98	0.57
Along	0.45	0.54	0.97	1.34

During the transition from across to along discharge, the degree of polydispersity is preserved, but the average size of fractions is doubled from ~0.6 to ~1.3 mm, which causes an increase in the efficiency of electric pulse crushing. The average size of the fraction realized is comparable to the average size of the products of mechanical crushing with a hammer crusher.

Summary

The results confirm the possibility of destruction of the PCB by high voltage pulse method. It is shown that when changing the orientation of the discharge channel relative to the PCB plane from across to along, a twofold increase in the productivity of the crushing process and the efficiency of converting stored energy into mechanical work is realized. The increase in the efficiency of the crushing process is due to a twofold increase in the average size of the fraction to 1.3 mm.
A high degree of release of elements >96 % in the fraction of + 1-2 mm was obtained. This fraction size meets the requirements of existing material separation methods.

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