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4.2 Determination of destruction conditions for substrates of flexible printed structures

The number of flexible printed structures (FPS) used in electronic products is constantly growing, based on the many advantages of such products compared to traditional printed circuit boards on rigid substrates and bulky cable products [235-236]. In light of the rapid development of flexible electronics around the world, the study of such structures is extremely relevant [237-238]. Flexible printed structures are used in mobile devices, in particular, for military, medical or space applications, etc.

Thus, it is advisable to use FPS in robotic mobile platforms, for which the size of structural elements, their weight and reliability are critical [239-240]. FPS can significantly reduce the overall dimensions of the hardware component of mobile platforms, while providing the possibility of three-dimensional installation, as well as their use in a dynamic mode under various external influences.

To conduct experimental researches, a test sample of FPS with dimensions of 100 mm × 30 mm, shown in Fig. 1, was used. The FPS under test is made of polyimide foiled with aluminum of material type FDI-A-50 (with a thickness of polyimide layer of 20 μm and aluminum foil of 30 μm) by subtractive technology.

The objectives of experimental research are:

– determination of the base material electrical strength under normal operating conditions and under conditions of use in environments with high humidity, as well as the impact of sea water on the insulating base;

– assessment of the tensile strength level of the polyimide substrate;

– analysis of the nature of FPS deformations under dynamic mechanical influences.

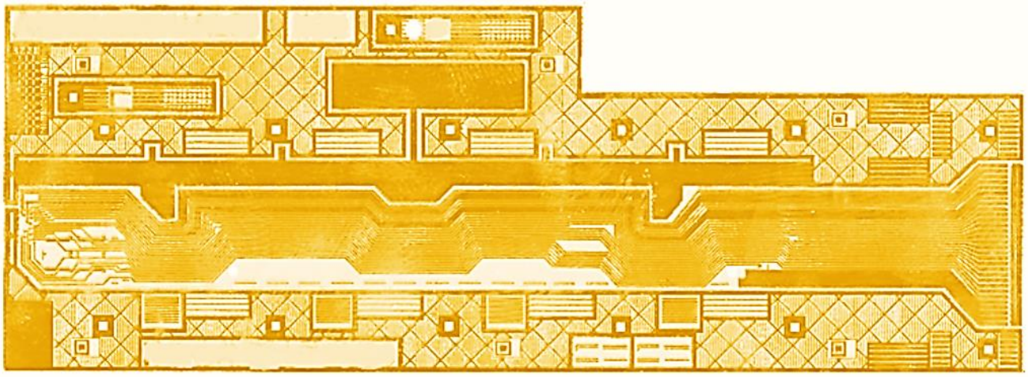


Figure 1. General view of the test sample.

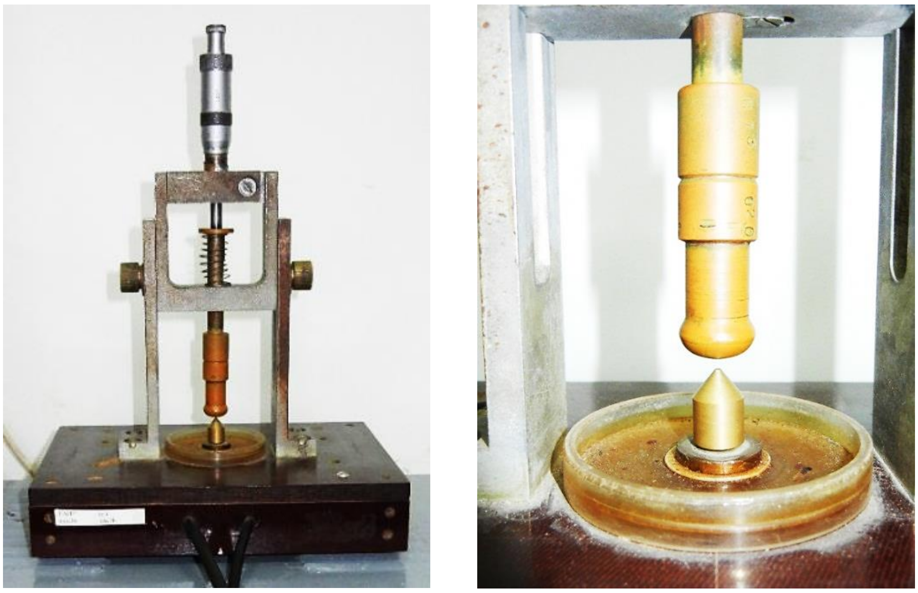
The electric breakdown of solid dielectrics is based on electronic processes of impact ionization. Breakdown occurs instantly, does not depend on the time of stress and is associated with the destruction of the molecular and crystalline material structure. The determining factor for it is the electric field strength.

To study the electrical breakdown mechanism for the dielectric substrate of polyimide FPS the universal breakdown system UPU-1M is used. The stand is designed for testing insulation materials with alternating sinusoidal voltage with a frequency of 50 Hz and rectified voltage of negative polarity, adjustable from 0 kV to 250 kV with an output current of up to 100 mA. This stand is used in electrical engineering and power engineering. It is designed for operation indoors or under a canopy at operating values of air temperature from 5 °C to 40 °C, relative humidity up to 80% (at a temperature of 20 °C) and atmospheric pressure from 84.0 kPa to 106.7 kPa. Power supply is single-phase network of sinusoidal alternating current with voltage of (220 ± 20) V and frequency of (50 ± 1) Hz.

The physical configuration of UPU-1M, as well as the design of the electrodes are presented in Fig. 2, a and Fig. 2, b, respectively.

To conduct the experiment, the FPS test sample was fixed between the contacts of the UPU-1M unit, after which there was a gradual increase of the electric field strength in the area of the test sample.

As a result of the experiment, the value of the breakdown voltage of the FPS substrate, which is operated under normal conditions, was fixed at the level about 25 kV.



a) b)

Figure 2. UPU-1M stand configuration (a) and design of electrodes (b).

The view of FPS test sample after the electric breakdown is presented in Fig. 3.

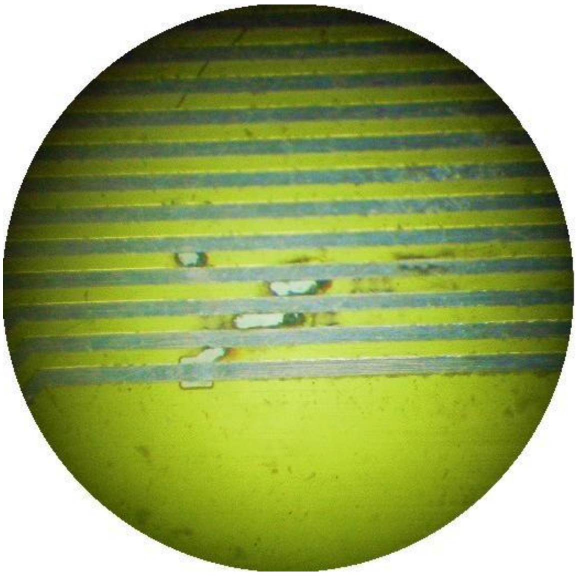


Figure 3. View of the test sample after electrical breakdown.

As can be seen from Fig. 3, the dielectric base of the FPS has undergone mechanical damage in the region of maximum concentration of the electric field strength.

To conduct an experiment for determining the ultimate electric field strength that causes the breakdown of the FPS substrate during its operation in conditions of high humidity the test sample was placed in water for several days. After extraction and drying, the FPS was placed between the contacts of the UPU-1M unit and examined for electric breakdown.

During the experiment it was found that the breakdown of the dielectric base occurs at a voltage of about 35-40 kV. The test sample has the form shown in Fig. 4.

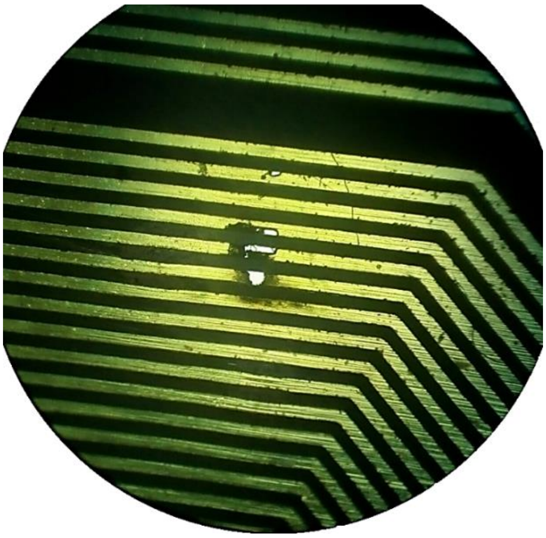


Figure 4. View of the FPS test sample, operating in conditions with high humidity, after an electrical breakdown.

As can be seen from Fig. 4, the area of mechanical failure is more localized than the area of destruction of the sample, which is operated under normal conditions. This result is due to the fact that the second sample was more degreased and purified.

To conduct an experiment to determine the maximum voltage required to break the base of the FPS by simulating its operation in the marine environment, the test sample was in salt water for several days. After drying, FPS were also subjected to an electric breakdown test.

As a result of the experiment, it was recorded that the breakdown of the dielectric base occurs at a voltage of about 35 kV. The test sample has the form shown in Fig. 5.

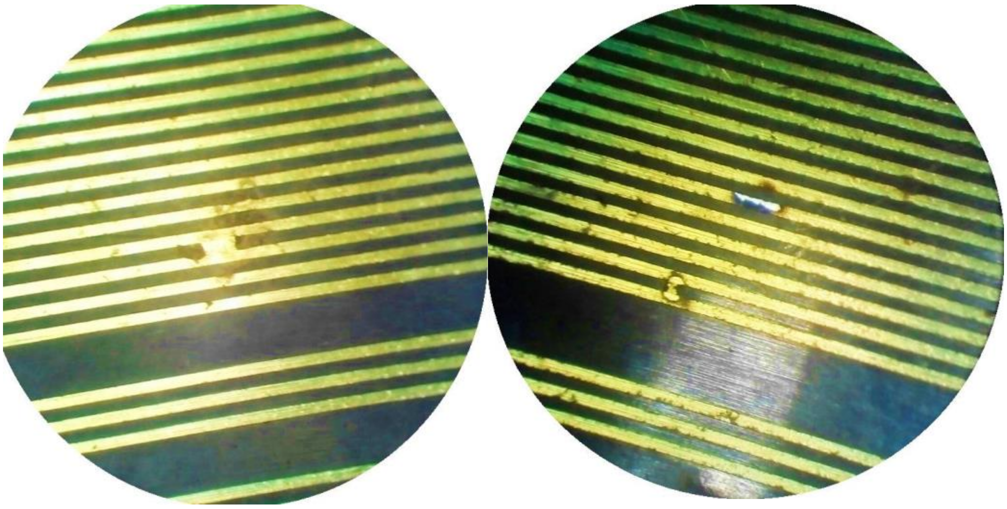


Figure 5. View of the FPS test sample, operating in conditions with high humidity and salt concentration, after an electrical breakdown.

To study the conditions of FPS mechanical breaking, the tensile testing machine IR 5047-50 was used, which is designed to test polymer products for rupture and deformation with a maximum ultimate load of 5000 kgf at normal temperature. The machine is designed to work in laboratory-type rooms.

For experimental research, the test samples were fixed in the tensile testing machine IR 5047-50, after which they were subjected to stretching. As a result, it was found that the rupture of a single-layer FPS based on polyimide FDI-A-50, shown in Fig. 1, occurs at a load of 10-12 N.

As a result, the test samples have the form shown in Fig. 6.

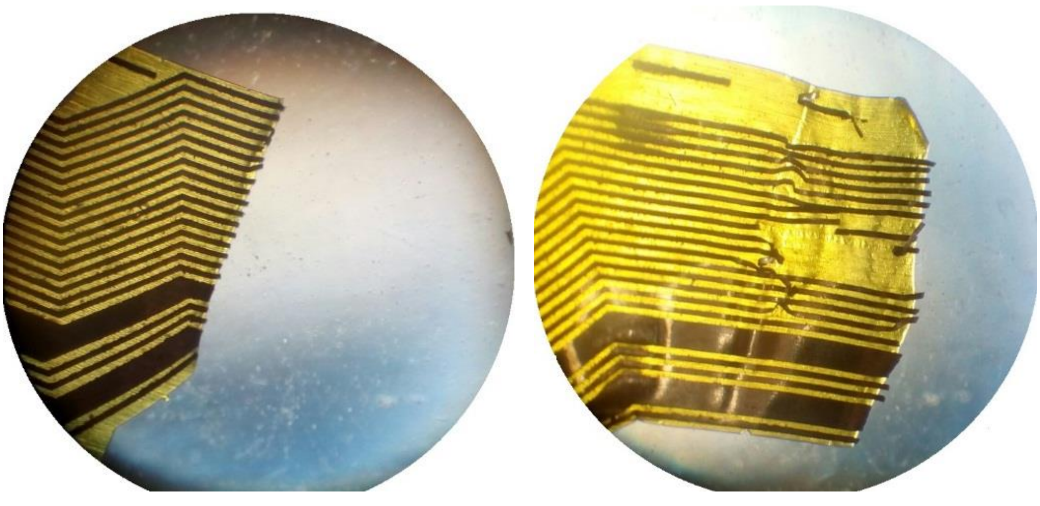


Figure 6. The test samples of FPS after rupture test.

To study the results of the influence of alternating loads, as well as the magnitude of the pressure that can lead to the destruction of the detachable contact joint (for example, FPS connection with ZIF-connector), a stand for dynamic research was developed [241]. It allows to create pressure on any area of FPS with a force from 0 N to 70 N, as well as alternately affect different sides of the FPS in the transverse plane with a frequency from 0 Hz to 100 Hz. The schematic design of the experimental stand is presented in Fig. 7.

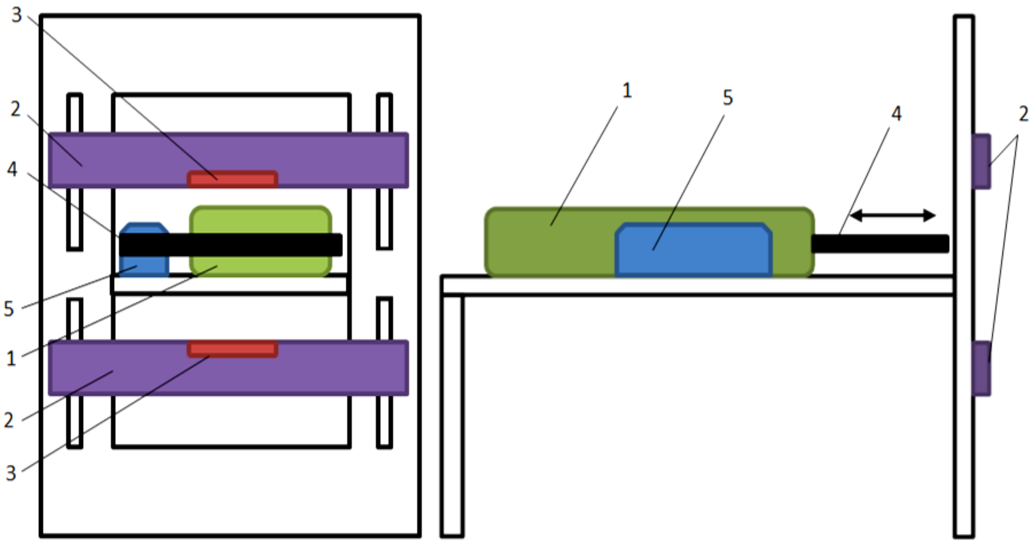


Figure 7. Experimental stand for dynamic FPS tests.

There are such position in Fig. 7: *1* is pusher made on the basis of the solenoid, with the possibility of operation in both directions depending on the polarity of the applied voltage; *2* is vertically movable parts of the frame for FPS mounting, which are made on the basis of printed circuit boards and allow to set different tension and position of the FPS; *3* is 40-pin ZIF-connectors for electrical and mechanical connection of the flexible loop with the rigid part of the electronic module; *4* is part with a slot in which a flexible loop is placed for further impact of the translational movement of the pusher; *5* is PCB for pusher operating mode control.

The working field of this stand has the sizes of 150 mm × 70 mm that allows to fix test samples of FPS of the corresponding sizes having a different configuration of printed conductors and a wide range of thickness of a dielectric substrate.

For the experiment, a test sample (Fig. 1) with a group of contact pads (Fig. 8) was fixed with a ZIF FPC-connector so that the maximum impact of the pusher took place in the area of the connector.

The pusher exert influence on the FPS test sample with increasing force (from 0 N to 5 N) until the latter was pulled out of the connector.

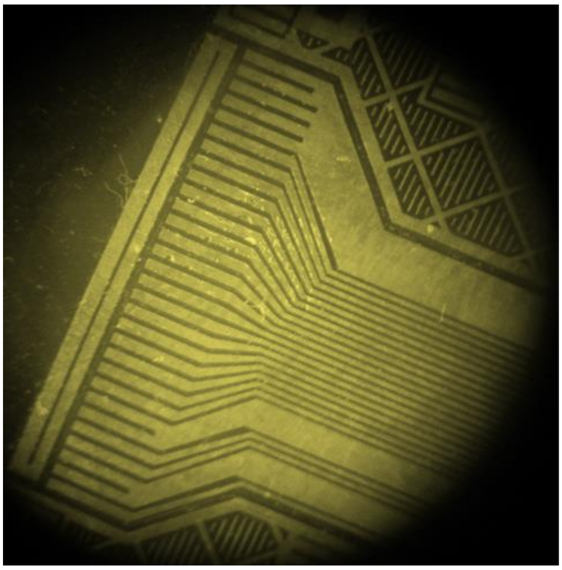


Figure 8. Terminal printed contacts of the FPS test sample.

As a result of the experiment, it was determined that with force $F \approx 5$ N the investigated FPS are pulled out of the connector, the samples then have the form shown in Fig. 9.

As can be seen from Fig. 10, in these areas on the sample there are significant deformations of the conductors, namely: their exfoliation (*1*); curvature of the edges (*2*); open circuits (*3*); formation of cracks on the surface of conductors (*4*).

Based on the results of the experiment, it can be concluded that with increasing force, which is aimed at the destruction of the detachable contact joint made on the basis of ZIF FPC-connector, there is a deformation of the conductive tracks of the FPS.

These changes can cause breaks or short circuits in the electrical circuits of the FPS, which in turn will increase the probability of failure of the entire product in which the FPS is used [242].

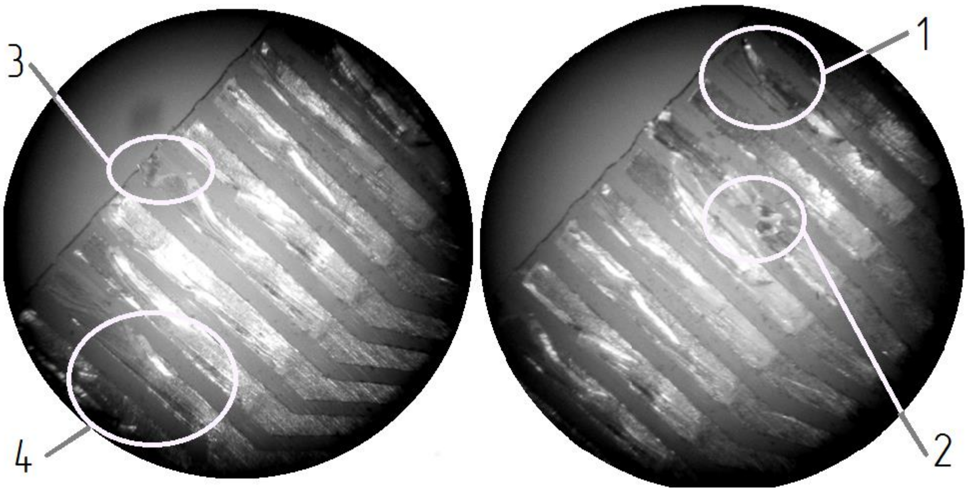


Figure 9. The FPS samples after the experiment.

Thus, the results of the destruction conditions determination for polyimide substrates for electronic products are presented. The breakdown voltage for different operating conditions of the FPS has been determined, it varies in the range from 25 kV to 40 kV. Using a tensile testing machine, critical levels of mechanical impact on FPS during their operation, which can lead to the destruction of polymer substrates, as well as of printed conductors on them, have been determined, it was in the range from 10 to 12 N. Studies performed using a stand for dynamic FPS testing allowed to determine the pressure value required to break the detachable contact joint of FPS and ZIF-connector, it was about 5 N.

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