Influence of external impact on secondary emission characteristics of anti-multipactor nanocarbon

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Abstract. This work demonstrates that a thin nanocarbon film applied to a metal surface is capable of decreasing the coefficient of secondary emission down to the value of 1 ÷ 1.5. Thereby, eliminating the possibility of a multipactor discharge. In this paper we describe a method of making an anti-multipactor coating from a colloid solution of nanocarbon. The colloid solution of nanocarbon is made by creating a multi-spike high voltage pulse discharge in ethanol where argon is injected into the inter-electrode space. Thermal, climate and tear-off tests have shown that emission properties of the surface are retained.

1. Introduction
In the past 20 – 30 years there has been an increasing interest in the study of multipactor discharges. The effect amounts to an exponential increase of electrons in vacuum due to secondary electron emission (SEE) caused by high power density of electromagnetic waves. This phenomenon can disrupt the operation of microwave generators, electron accelerators and lead to serious malfunctioning of satellite communication systems [1, 2].

This type of discharge may be exited in the presence of one or two surfaces. In the former case there must be an electric field which returns the electrons back to the emission surface.

The study of the multipactor discharge allowed to underpin the nature of this effect [3-5]. There are two types of such discharges, a resonance discharge and various types of a polyphase discharge. A resonance discharge is a type of discharge where electrons are sort of in resonance with the electric field, the thermal energy of the electrons is negligible and is not accounted for. Whenever the thermal energy is accounted for it gives rise to polyphase discharges [6-8].

In order to prevent the formation of multipactor discharges, the SEE coefficient $\sigma$ must be limited, $\sigma \leq 1$. In case of the polyphase discharges, $\sigma$ increases significantly and may reach to the limiting value of 1.96, when the discharge cannot be ignited.

Research into the method of how to suppress such effects is rather topical today, in particular for the satellite systems. The technology, which aims to solve the problem, primarily focuses on changing surface properties. In the works of [9] the authors demonstrated the decrease of the secondary electron emission down to the value of 1.4. However, the disadvantage of the method is due to the associated technological complexity and the fact that these effects decay with time. A greater decrease has been
achieved by creating micro roughening of the microwave capillary plasma jet [10]. However, the draw back of this method is a technical difficulty of scaling up the method for mass production and a possible increase in surface loses. Another method of decreasing SEE is by applying a thin nanocarbon film on a metal surface [11-13]. One of the advantages of the method is its simplicity. Carbon (soot) has a low SEE coefficient, is chemically neutral – chemically stable up to the temperature of 400 degrees Celsius. However, the use of soot is limited due to low adhesion properties.

The goal of this paper is to demonstrate the stability of the surface characteristics with respect to external impacts. A number of results from climate, thermal and tear-off effects to which the surface was subject to are demonstrated in order to illustrate its effectiveness (Figure 1). We have described the method of how such surfaces can be attained and the colloid solution used.

The surface was made on an Al plate by evaporating the colloid nanocarbon solution, which comprises of an amorphous carbon in sp² phase. The thickness of the film is approximately 1 μm. A stable colloidal solution of nanosized carbon was obtained by means of a highvoltage pulse discharge in ethanol solution and argon injection into the interelectrode space [12, 14].

2. Nanocarbon colloid solution

Highvoltage discharge facilitates creation of metastable carbon states as a result of atomization of an ethanol molecule in a high temperature discharge channel with a subsequent fast cooling. For implementation of the above method a multi-electrode discharge device is used [14,15], which is depicted schematically in Figure 2 together with the associated electrical circuit, where 1 – is a cylindrical dielectric chamber with the volume of 100 cm³, 2 – are electrodes on the inner side of the chamber which are evenly spaced with distance in between approximately 1-1,5 mm, 3 – electrically insulating material, 4 – are nozzles for Argon supply into the chamber with a diameter ≤1 mm, 5 – are terminals for the high voltage supply. The electrical circuit characteristics are the following: energy of a reservoir capacitor W≤1,6 J, voltage - U≤20 kV, current - I≤300 A, impulse frequency - f≤100 Hz. We have used 95% ethanol solution with Argon usage of approximately 2 l/min.

Figure 1. An electron microscope photograph of a nanocarbon film, obtained by evaporation of the colloidal solution.

Figure 2. a – schematics of the discharge device, (1 – dielectric pipe, 2 – electrodes, 3 – nozzles for gas supply, 4 – insulating material, 5 – working surface area of the electrode); b – an equivalent electrical circuit diagram. (1…7 – electrodes, 1’,…,6’ – gas nozzles, R₁-R₆ – equivalent resistance between the electrode and the earth).
Once the high voltage is applied, a high temperature discharge channel is formed within a gas bubble, which contains ethanol vapor. These channels have the following characteristics: temperature of heavy particles is 4000–5000 K, temperature of electrons is 1–1.5 eV, electron density is \( (2-3) \times 10^{17} \) cm\(^{-3} \). A detailed description of the setup is presented in [15].

Figure 2b displays an electrical circuit for the experimental set up. The whole systems follows the principle of a sliding discharge. Equivalent resistance, \( (R_1 \ldots R_6) \) is the ethanol resistance between the respective electrodes and the earth. The high value of ethanol resistance ensures the formation of a sliding discharge.

Figure 3 depicts an oscilloscope diagram for currency, voltage and the associated power. Under the discharge influence the ethanol solution acquires a dark brown color.

Parameters of the colloidal solution were studied in a number of ways using an electron microscope JEM – 2100 together with an energy dispersal x-ray spectrometer JED – 2300: Raman scattering (RS), dynamic scattering (DSL). We have determined the following characteristics of the colloidal solution:

- A stable colloidal solution is obtained via an increase of the energy density of the solution \( \sim 10 \ldots 15 \text{ J/cm}^3 \). Energy density is defined as electric energy acquired by the charge per unit volume of the ethanol solution. Stability of the colloidal solution is verified over an observation period of 2 years with the measured z-potential of \(-32.3 \text{ mV}\).

- By increasing the temperature of the solution close to the boiling point and subsequent cooling does not change its properties.

- Part of charged particles are negatively charged.

- The size and structure of the nanoparticles depend on the energy density (the size distribution of particles for energy density close to the threshold of discharge stability is depicted in Figure 4)

Our chemical analysis has shown that \( \sim 70 \ldots 80\% \) of the solution is Carbon, \( \sim 1 \ldots 2\% \) is atomized metal from electrodes, while the rest is oxygen.

3. Thermal, climate and tear-off trials
There is a number of characteristics expected from anti-multipactor surfaces which are presented in [9]. These are:

- Low secondary electron emission coefficient (the first critical potential \( E_1 > 75 \text{ eV} \), with the value of SEE coefficient - \( \sigma_{\text{max}} < 1.5 \));
- Stability to strong temperature fluctuations;
- Low radio frequency surface resistance (which does not exceed the resistance \( \text{Ag} \) by a factor of more than 3);
- Stability of film characteristics in atmospheric conditions for a duration of at least 10 months.
The film derived from our method fulfills all the requirements for the anti-multipactor surfaces. The method is based on creating a nanocarbon film on the surface of a metal and is intended for the use in outer space communication equipment. It has been shown in [16] that the film does not interfere with the works of the radio equipment and its elements. The film reduces the SEE to the value $\sigma_{\text{max}}$ down to $\approx 1$, secondary emission properties are retained with time (for more than 1 year in atmospheric conditions).

In order to validate that such films are good candidates for a practical use in space equipment. Below we present our experimental findings done on a Al plate (1x1x0.1 cm$^3$):

- Tear-off effects (tape method performed several times);
- Accelerated climate trials (ACT) – an increased temperature of up to 70 °C for a 10 day period, 95 % humidity at 30°C for a 3 day period;
- Thermal cycling – 10 cycles of temperature fluctuations from -160°C to +160°C at a speed of 5°C/min at a pressure of $5\cdot10^{-5}$ mm of mercury.

Figure 5 depicts photographic images prior and after thermal cycling and accelerated climate trials. Accelerated climate trials were aimed to model 2 years of preflight preparations in terrestrial conditions. Thermal cycling trials were chosen to resemble true satellite equipment’s conditions as close as possible. It is from the photograph that the film remains intact.

Photographs from tear-off experiments are shown in Figure 6. As a result of tape tear-offs a thin layer of the film was removed from the top. The remaining film retains good adhesion properties.

The RS of the film are depicted in Figure 7. The wavelength of a laser is 514 nm. The resultant spectrum, for prior and after the experiment, looks almost identical with two distinct peaks D and G (1350 and 1595 cm$^{-1}$, respectively).

This suggests that for the most part the coating consists of carbon in the form of graphite nanoparticles. The distribution of colloidal particles is depicted in Figure 4. The ratio of intensities of
the two peaks D and G indicates the presence of small graphite nanoclusters. The size of graphite nanoclusters can be estimated from the ratio of intensities of D and G components of the spectrum. [17]. Since, after removing the top layer only insignificant changes were observed, the ratio $I(D)/I(G)$ is $0.75 \pm 0.05$ in both cases. Therefore, the size of graphite clusters is estimated to be 1-1.5 nm.

Figure 8 displays the secondary electron emission coefficient as a function of energy of the electron bundle for various types of trials (8a - a plane aluminum plate without the film, 8b – prior to the experiment, 8c – after the experiment).

The measurements of SEE were carried out as described in [10]. From the above results it follows that the film properties are retained after the trials. Also, it is worth mentioning that in [16] it was shown that the film does not influence electronic properties of the equipment. This film was tested on real elements of satellite equipment (a microwave valve) [16].

Functional compatibility was also tested, no deviation from the standard workings of the valve were observed.

4. Conclusion

The above results indicate that the suggested nanocarbon film on the surface of a metal fulfils the required characteristics of an anti-multipactor surface. The method is cheap and simple and therefore can be effectively applied to a variety technological tasks for example [18].

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