CROSS-FIELD MULTIPACTOR DISCHARGE IN X-BAND CYLINDRICAL CAVITY

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Abstract

The paper represents the experimental study of one-sided cross-field multipactor discharge in the copper cavity with the operating mode TM_{01} in external DC magnetic field. It was shown that discharge is very sensible to magnitudes of the external magnetic field and rf fields as well. At proper fields the multipactor discharge can be developed for 15 ns and the electron concentration can be comparable with critical one for the given rf frequency. As a result of discharging, the cavity changes its own resonant frequency and can play a role of a switch which can substitute full transmission by full reflection. Switching parameters could be controlled by DC magnetic field as well as by additional rf radiation at different frequency than operating frequency. The high rf absorption of multipactor discharge is also can be used in electrically controlled powerful loads and attenuators.

INTRODUCTION

A one-sided multipuctor in vacuum can be developed in cross-field RF electric and DC magnetic fields near wall of a cavity or a waveguide under a specific ratio of a cyclotron frequency and a RF frequency [1]. In X-band maximum of absorbed RF power can reach tens of kW per square centimeter [1, 2]. High multipactor discharge currents allow using this phenomenon to push resonant frequency of a cavity [3]. These properties of the one-sided multipactor make it attractive to MW power level applications where waveguides or cavities play a role of switches or controllable attenuators.

LAYOUT OF THE EXPERIMENT

A cross-field multipactor discharge is developed in time and at surface as well. In particular, let us consider a TM_{01} cylindrical cavity with an axial magnetic field. At the surface of such cavity there are necessary cross-fields (Fig. 1 a) in which electrons are able to oscillate periodically along the surface and to hit many times this surface. As a result electrons multiply itself, and the discharge current grows up to a saturation level.

The structure of the electric RF field in the cavity is shown in Fig. 1b. Q-factor of the cavity equals 420. It was chosen in order to electron layer of the saturated discharge with concentration close to cut off level would decrease an effective radius so that resonant frequency would increase more than a bandwidth of the cavity..

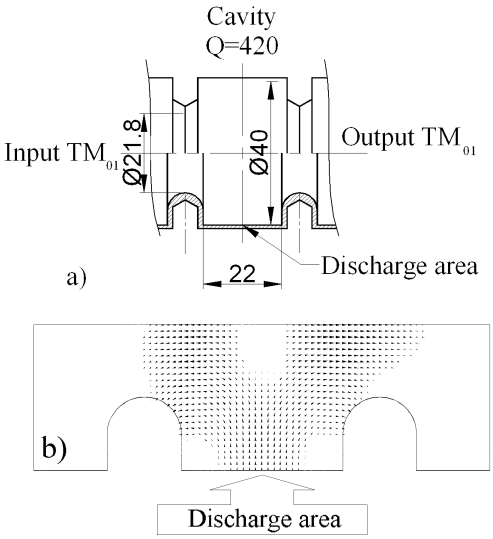

Figure 1: Drawing of the X-band test cavity (a) and electric field structure (b).

In order to provide maximum vicinity of conditions for discharges in this experiment and for previous successful experiments carried out in a rectangular waveguide [2], the side surface of the cavity was made of “L-96” bronze alloy (Cu – 96%, Zn – 4%) as it is used in standard waveguides. The rest part of the cavity including connecting waveguides was made of the oxygen free copper. Estimations show that the observed in [2] absorbed RF power, which determines discharge current and electron concentration at saturation regime, corresponds to secondary emission coefficient $\sigma \approx 1.6$.

To pump the test cavity, put in a vacuum chamber *4* (Fig. 2), longitudinal holes in walls of input and output waveguides *6*, *10* were made. These holes did not perturb the operating TM_{01} mode. At input and at output of the mentioned circular waveguides barrier windows *3*, *11* were installed which consisted of thing mica films. Tests were carried out under continuous thermal degas of the chamber *4* by means of the special heater *5* which provided temperature rise up to 600°C. Vacuum at level 5×10^{-7} Torr was kept. As RF source we used a magnetron with output power

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up to 250 kW with tunable frequency from 9.13 GHz to 9.5 GHz. RF radiation by means of the mode converters *1* and *2* was converted from the TE_{10} mode in a rectangular cross-section waveguide into the TM_{01} mode of a circular cross-section waveguide. To control incident, reflected and transmitted powers, directional couplers in rectangular waveguides were used.

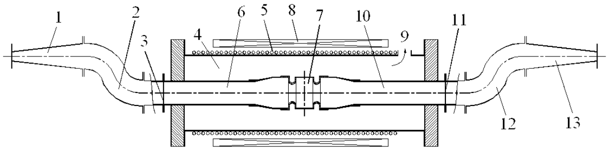

Figure 2: Scheme of experiment: 1, 2, 12, 13 –TE10 of rectangular waveguide to TM01 of circular waveguide mode converters; 3, 11 – barrier windows; 4 – vacuum chamber; 5 – heater; 6, 10 – circular waveguide with longitudinal holes for pumping (cavity input and output); 7 – test cavity; 8 – solenoid; 9 – vacuum pump.

EXPERIMENTAL RESULTS

Investigations have shown that in accordance with calculations multipactor discharge at magnetic field 0,17 T (a condition for the first discharge mode) exists and causes cavity detuning so that reflected and transmitted powers are changed essentially. In Fig. 3 typical oscillograms are shown when magnetron frequency initially was tuned exactly to the resonant frequency ogf the cavity. As one can see the discharge is fast enough to be developed at front of RF pulse, and as a result the magnitude of the transmitted signal drops by two times, simultaneously power of the reflected signal increases.

Investigations show that at condition of an equality of the magnetron frequency and the central cavity frequency the discharge initiation and cavity tuning/detuning caused by this discharge take a place in broad band on power P_{in}. If one increases incident power from pulse to pulse, a time when discharge starts goes to RF pulse beginning, the reflected power P_{refl} grows up, the transmitted power P_{tr} as well as the absorbed power P_{abs} go down. This is illustrated by plots in Fig. 4. The mentioned events are associated with self matched regime (see [3]), where a balance between cavity detuning strength, the obtained electron concentration, and RF field magnitude in the actually detuned cavity occurs. This balance determines a ratio of the incident, reflected, and transmitted powers. As a result the test cavity became more efficient as a switch when incident power was bigger.

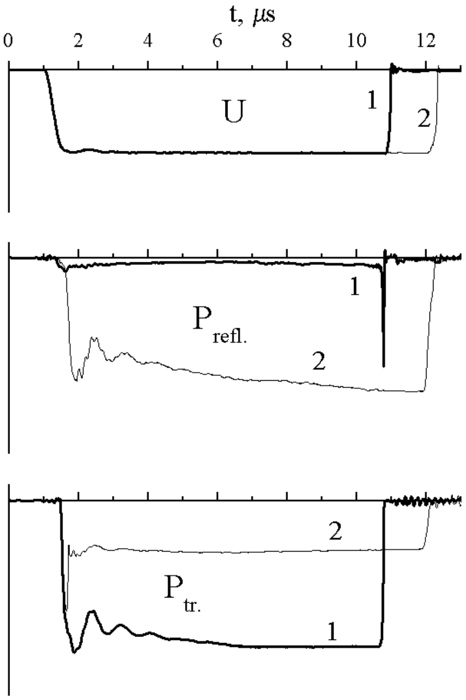

Figure 3: Oscillograms of voltage at magnetrone *U* and RF signals, reflected by cavity P_{refl} and transmitted P_{tr} at incident RW power 80 kWт. Curves 1 corresponds to case, when magnetic field is switched off, curves 2 – with magnetic field switched on.

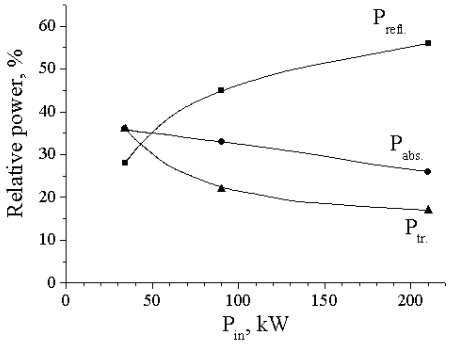

Figure 4: Dependence of relative reflected power P_{refl}, absorbed power P_{abs}, and transmitted P_{tr} power on incident power P_{in}.

In Fig.5,a one can see dependencies of the transmitted power with developed multipactor normalized on transmitted power without multipuctor as a function of an external magnetic field represented by a ratio of a cyclotron frequency to RF frequency $\gamma = \omega_c/\omega$ under different incident powers. It is remarkable that multipactor appears at smaller

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magnetic fields and in a more broad region on magnetic field in comparison with experiments [2].

These observed effects can be explained by additional factor playing a role in cylindrical systems. In cylindrical cavity RF field increases out of surface. This means an existence of additional returning force (pondermotive force) which perturbs electron motion.

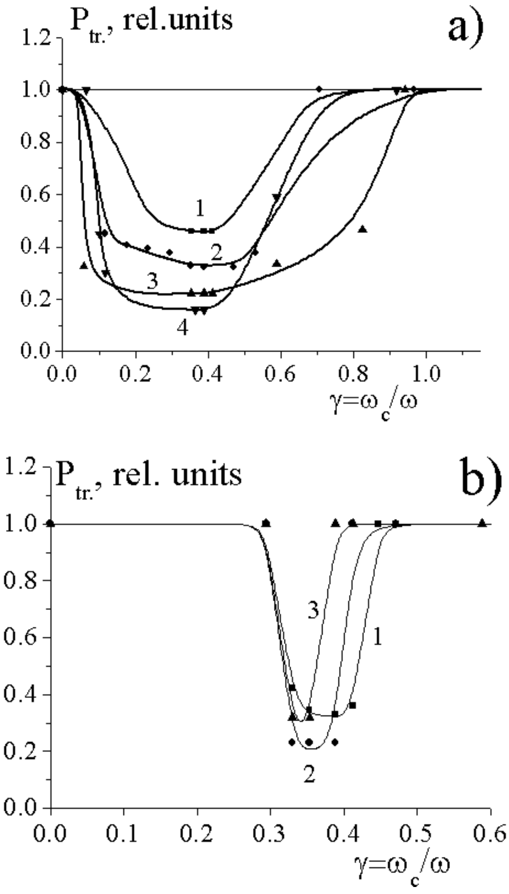

Figure 5: Dependence of transmission P_{tr} on magnetic field γ under different input RF power. (a) – temperature 400°C; 1 – 25 kW; 2 – 45 kW; 3 – 75 kW; 4 – 190 kW. (b) – temperature 600°C; 1 – 90 kW; 2 – 140 kW; 3 – 175 kW.

In Fig. 5 a,b graphics are shown, which were obtained at temperatures of the cavity 400^0 C and 600^0 C respectively. Investigations show that at 600^0 C the gap of magnetic fields, at which the discharge can be developed, is reduced one can observe also reduction of the transmitted power. In addition the higher power the more narrow magnetic field gap, the discharge becomes unstable, and at maximum of input power the discharge cannot be developed at all. The gap of the discharge's existence becomes more narrow in comparison with a discharge in a waveguide [2] and is shifted by 15-20% in a region of smaller magnetic fields. Such the observed temperature effects can be explained so that amount of the surface admixtures is reduced at high temperature, and as a result the secondary emission coefficient σ also drops. Therefore, high-order multipactor modes could be suppressed and the gap of magnetic fields for the main mode could be made more narrow. Additional cause of discharge supression at highest powers could be explained by RF field inhomogenities at cavity surface.

In experiments we have measured a threshold on electric field which is responsible for an essential change of transmission and reflection. It was found out that initiation of the discharge requires fields higher than ~15 kV/cm, but in order to keep this discharge one needs 8 – 10 kV/cm only. Grows of the multipactor and detuning of the cavity cause automatical decreasing of all fields due to reflection of RF power. Therefore, there is a hysteresis which can be explained in a way that at the initial stage of the multipactor one needs the highest level of the secondary emission coefficient or the highest dark currents in order to compensate destroying forces like a pondermotive force. Anyway this leads to a necessity to provide high enough RF fields. At stage of the already developed multipactor the mentioned defocusing forces become less due to a correction of a field distribution by spatial charge of the born electrons.

CONCLUSIONS

The carried out experiments have shown that multipactor can be initiated very fast (for a time like 15 ns), the electron concentration can obtain close to critical for a given frequency values (~ 10^{12} cm^{-3}), as a result a cavity can be switched on/off so that full transmission goes to full reflection. This property can be used to build fast, high-power RF switches to be controlled by magnetic fields or external RF radiation of a moderate power. The studied multipactor can be also used for controllable RF loads which can absorb high-power RF radiation.

Experiments show that multipactor can attend in relativistic high-power devices, in particular, multipactor discharge can arise in relativistic Cherenkov BWOs operated with TM_{01} и TM_{02} modes.

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