Experimental investigation of powerful THz gyrotrons for initiation of localized gas discharge

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***Abstract*—Results of experimental tests of a high-power sub-terahertz gyrotron with a pulse solenoid are presented. The operating frequency corresponds to the atmospheric transparency window (0.66-0.67 THz). The output power up to 200 kW in single 50 microsecond pulses was obtained. The 0.3THz / 0.5 MW tube is under experimental tests. Gas discharges have been realized in a wide range of pressures (0.01 - 1500 Torr) and different gases. Such discharges can be used as the pointed source of UV/VUV radiation, including the projection lithography.**

I. INTRODUCTION

AT present, there is a strong interest in developing powerful sources of the terahertz (THz) radiation for numerous applications such as, for example, localized gas discharge [1]. The promising radiation source for this application is a gyrotron. To mitigate the problem of mode competition, the operation at the fundamental cyclotron resonance is preferable. For such THz-range gyrotrons magnetic fields should be well above those available from cryomagnets. Therefore gyrotrons with pulse solenoids are the only option in this case.

II. DESIGN AND MAIN PARAMETERS OF PULSED GYROTRONS

A demountable THz gyrotron tube with a 28 T pulse magnet has been designed, constructed and tested. The solenoid was made of a copper cable wired directly on a thin stainless steel gyrotron body. For reducing ohmic heating and stabilizing the operation, the solenoid was cooled by liquid nitrogen. Due to limitations caused by cooling of the pulsed solenoid, the repetition rate was limited by one shot in three minutes. Gyrotron components included the conventional cylindrical cavity made from a special sort of bronze and the diode-type magnetron injection gun. The high-voltage pulse was synchronized with the peak of the pulsed magnetic field. The tube was equipped by a quasi-optical external mode converter of the operating mode into a Gaussian wave beam. The output power about 200 kW has been obtained [2].

The demountable 0.3 THz gyrotron with a pulsed coil has been also developed. The calculated output power is about 0.5 MW with pulse duration about 30 microseconds. The experimental facility is shown in Figure 1. The left tube is a 0.3 THz gyrotron, the right one is a 0.7 THz gyrotron with installed external mode converter to narrow wave beam, connected to the vacuum chamber for plasma experiments.

III. GAS DISCHARGE EXPERIMENTS

The main goal of the development of such gyrotrons is initiation of a localized gas discharge. One of possible applications is the remote detection of concealed radioactive materials [3]. Another goal is to use the discharge plasma supported by THz radiation as a source of EUV light for high-resolution lithography. A self-sustained discharge could be maintained in the pressure range from 20 Torr to two atmospheres. By using several methods of discharge initiation it was possible to expand the range of discharge existence to much lower pressures down to about 0.01 Torr. It was shown that the low pressure (dozens of Torr and less) discharge has a number of features compared with the discharge at high pressures: the presence of the powerful afterglow lasting for about 20-50 microseconds after a gyrotron pulse, the lack of a strongly inhomogeneous spatial structure of the discharge glow (at pressures less than 10 Torr), the lack of screening of the discharge appearance location from the gyrotron radiation. The size of the plasma discharge at the pressure of 0.01 Torr in Argon was about 1 mm. The dynamics of the microwave breakdown in air was simulated numerically within a simple 1D model which takes into account such processes as the impact ionization of gas molecules, the attachment of electrons to neutral molecules, and the plasma diffusion. Calculations were carried out for different spatial distributions of seed electrons with the account for reflection of the incident electromagnetic wave from plasma. The results reveal that the lowering of the gas pressure as well as the increasing of the electromagnetic wave frequency lead to significant modifications of the ionization wave.

Fig. 1. Photo of experimental setup.

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