DEPENDENCE OF MAGNETRON CHARACTERISTICS ON THE SECONDARY-EMISSION YIELD OF COLD CATHODE

N.I. Avtomonov, S.V. Sosnytskiy, D.M. Vavriv
Institute of Radio Astronomy of NAS of Ukraine, Kharkiv
E-mail: avtomat@rian.kharkov.ua

Particle simulations of mm-wavelength magnetrons with cold secondary-emission cathodes show that such important practical characteristics as the output power, efficiency, and operation current are dependent on secondary-emission properties of the cold cathode used in such magnetrons. However, in some cases, the enhancement of the magnetron characteristics can be achieved with a relatively low secondary-emission yield of the cold cathode. This opens a way for using of pure inexpensive metals for the cathode production. The interplay between the secondary-emission yield and the magnetron performance is studied to realize this approach.

PACS: 84.40.Fe

1. INTRODUCTION

Magnetrons with cold secondary-emission cathodes were proposed as an alternative to conventional magnetrons in order to improve the lifetime of the devices, which is limited by the lifetime of thermionic cathodes. A cold, metal cathode is used as the main one, withstanding the powerful electron back-bombardment inherent in magnetron generators, while a small thermionic cathode, placed outside of the interaction space, provides an initial amount of electrons, which is then multiplied during the secondary electron emission on the cold cathode.

The first attempts to produce such magnetrons were not successful [1], however, on higher frequencies of generation, in the millimeter wavelength band, the secondary emission on pure metals gave enough current to support the oscillations [2].

In order to reach higher values of the secondary emission coefficient, platinum was chosen as the main material for the cold cathode. As long as the production of the cathode of solid platinum would be too expensive, the cathode is really made of a copper core plated with platinum foil, which makes the manufacturing process more complex.

Therefore, there is a practical need for new magnetron designs, utilizing cheaper cold cathodes with a simpler manufacturing procedure. In this work, possibilities of the development of such cathodes is theoretically studied for the case of a standard design of 8-mm wavelength magnetron produced at the Institute of Radio Astronomy of NAS of Ukraine [2].

2. THEORETICAL BACKGROUND

The study of the influence of secondary-emission characteristics of cold cathode has been performed with the use of the self-consistent model of spatial harmonic magnetrons proposed in [3]. This model is based on 2-D particle simulation, i.e. electrons within the interaction space are represented with macroparticles, each of them corresponds to a large number electrons moving along close trajectories. In this work, the space-charge field was calculated on a mesh of 256 cells along the azimuth coordinate and 48 cells along the radial coordinate. The number of particles was about 30 000, and the time-step for solving the equations of motions was 0.0965 ps.

Within this model, the secondary electron emission from the cold cathode is taken into account in the following way. If, after obtaining new values of the particle coordinates, the radial coordinate is smaller than the cathode radius, it is assumed that the particle has impacted the cathode. Then, this particle is removed from the further calculations, and new particles modeling the secondary emission electrons are introduced instead. The number of the new particles is determined by the value of the secondary emission coefficient.

The secondary electrons can be divided in two groups: true secondary-emission electrons driven out of the cathode material, and primary electrons, inelastically reflected from the cathode surface. The difference between the secondary-emission properties of different materials usually can be described as difference in the maximum value of the true secondary emission coefficients (δ), while the difference in the inelastic reflection coefficient (η) are rather insignificant. Therefore, in this work, we have varied the true secondary-emission coefficient, although, for the sake of convenience, the integral secondary-emission coefficient is given in the discussion of the obtained results.

The dependences of δ and η on the energy of the primary electron (W_0) were the same as those of platinum [4,5], see Fig.1.

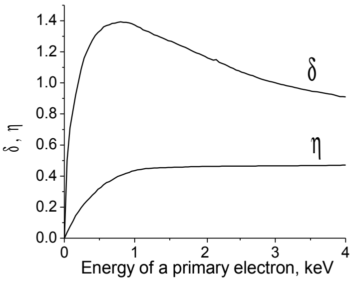


Fig.1. Dependencies of δ and η on the energy of primary electron for platinum

In order to take into account the dependence of the secondary-emission coefficient δ on the impact angle α, the following relation was used [6]:

$$\delta(W_0, \alpha)=\delta_0(W_0/(1+\alpha^2/\pi))[1+\alpha^2/(2\pi)],$$

where $\delta_0(W_0)$ is dependence of the coefficient of true secondary emission for normal incidence of primary electrons ($\alpha=0$) on the energy of these electrons.

ВОПРОСЫ АТОМНОЙ НАУКИ И ТЕХНИКИ. 2006. № 5.
Серия: Плазменная электроника и новые методы ускорения (5), с.225-228.

3. MAGNETRON DESIGN

The results presented below were obtained during simulation of a spatial-harmonic magnetron with cold secondary-emission cathode. It is designed for operation on the wavelength of 8 mm, and has the following characteristics: the anode radius, R_a =2.25 mm, the cathode radius, R_c =1.3 mm, the anode resonators' depth b=3.635 mm, the resonator opening α = 12.4°, the axial length, $L = 6$ mm, the number of the anode resonators N= 16, the magnetic field, B = 0.5875 T, the thermionic emission current, I_t =0.4 A. Two degenerated cavity modes were considered: TE_{31} with the natural frequency f of 36.4 GHz and TE_{41} with f= 38.11 GHz.

4. SIMULATION RESULTS

The magnetron described above was subjected to simulation of its operation under following conditions. The anode voltage was varied in the range of 12.6… 14.2 kV, which included the ranges of generation of the noted two modes, TE_{31} and TE_{41}. The effect of Q-factor was investigated by simulating two versions of the magnetron one with a high loaded Q-factor of 230, and another with a lower loaded Q-factor of 90.

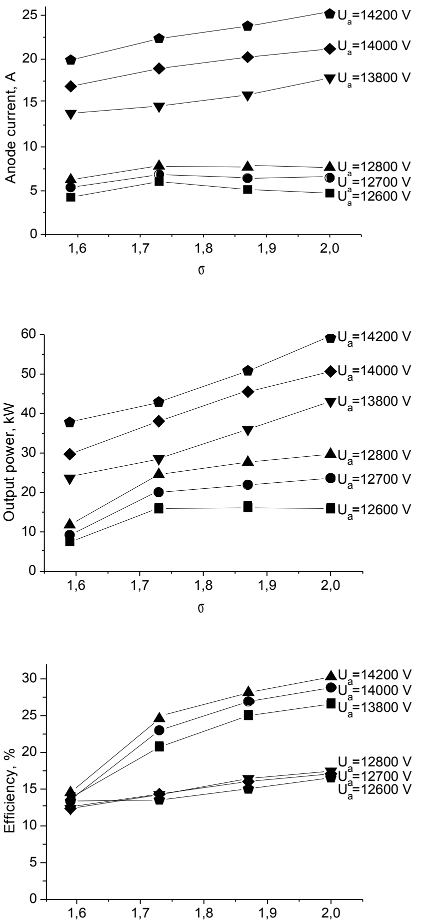
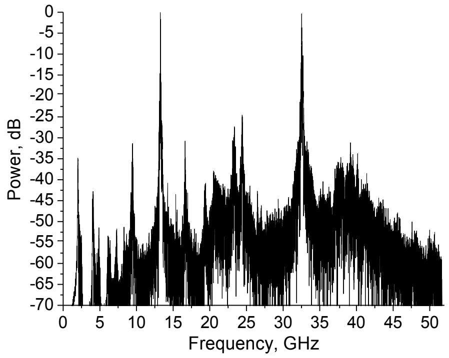


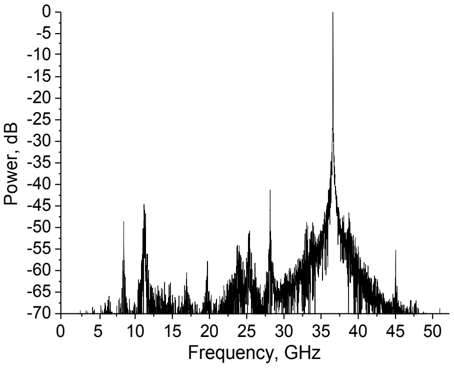
Fig.2. Anode current, output power, and efficiency versus the secondary-emission yield of the cold cathode for TE_{41} and TE_{31} operating modes

In Fig.2 one can find plots illustrating the results of the simulation for the low Q-factor cavity. It is seen, that in a wide range of anode voltages, variation of the secondary-emission yield results in increase of the output power, despite of the fact that the anode current value is not changed as much, or even remains almost constant (in the case of the TE_{31} mode).

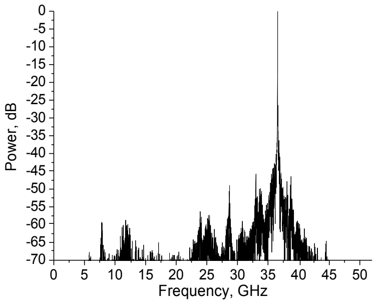
Another feature of the plots in Fig.2 is that either magnetron efficiency, or the output power plot has a steeper slope at lower values of the secondary-emission yield.



σ= 1.05



σ= 1.73



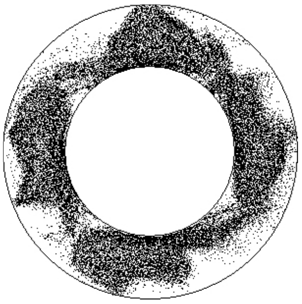
σ= 2.0

Fig.3. Spectra of the output signal for TE_{31} mode (U_a=12700 V) and for different values of the secondary-mission coefficient σ

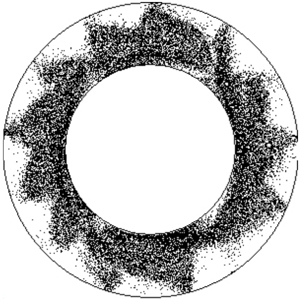
An important improvement provided by higher values of the secondary emission yield is a lower noise figure of the device. This can be seen in Fig.3, where the spectra of the output signal are given for different values of the secondary emission coefficient.

The complex spectrum of the output signal is caused by an irregular structure of the electron cloud within the magnetron interaction space. As seen in Fig.4, the higher is the secondary-emission coefficient, the more regular are the spokes formed during the interaction of electrons with the RF- field.

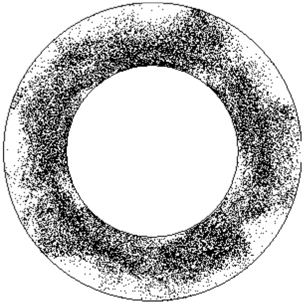
As our simulations have shown, a threshold value of the secondary emission yield exists. If the secondary electron emission coefficient does not exceed this value, generation of periodic oscillations becomes impossible. Instead, the electron cloud behaves rather chaotically, allowing some dc current to pass through the device, but giving a virtually zero output RF power. As seen in Figs.5, 6, this threshold value depends both on the Q-factor and on the mode of cavity oscillations.



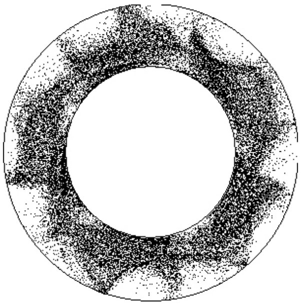
σ= 1.59, U_a = 12.7 kV



σ= 2.00, U_a = 12.7 kV



σ= 1.46, U_a = 14.0 kV



σ= 2.00, U_a = 14.0 kV

Fig.4. Space charge distributions for different values of the secondary-emission coefficient σ

It can be also noted, that in the case of the TE_{31} mode with low Q-factor on increase of the secondary emission yield much larger over its threshold value improves the magnetron efficiency and output power only slightly. It creates opportunities for designing magnetrons that utilize cheaper cold cathodes made of pure copper or molybdenum

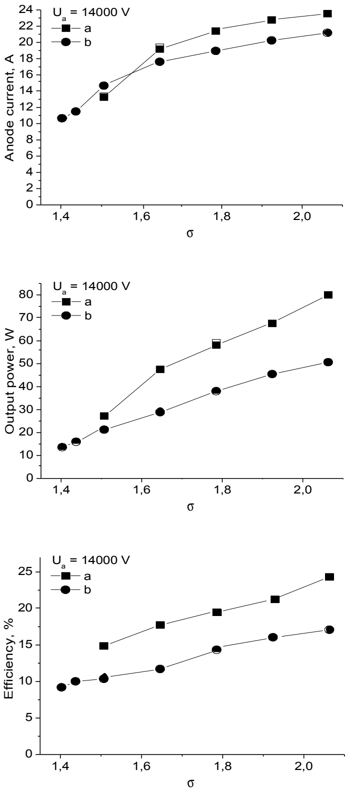


Fig.5. Anode current, output power, and efficiency versus the secondary-emission yields of the cold cathode for different values of Q-factor of TE_{41} mode: a –Q=230 and b – Q=90

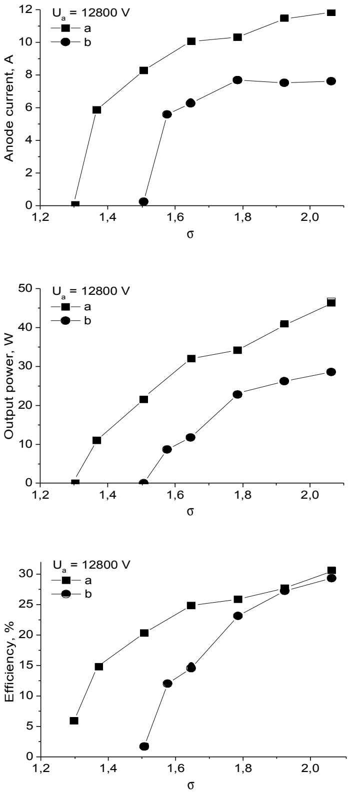


Fig.6. Anode current, output power, and efficiency versus the secondary-emission yields of the cold cathode

for different values of Q-factor of TE_{31} mode: a –Q=230 and b – Q=90

5. CONCLUSIONS

The performed numerical simulation of operation of spatial-harmonic magnetrons with cold cathodes has shown that, generally, an increase of the cold cathode's secondary-emission yield results in increasing of the efficiency and output power, and decreases the relative noise level.

However, this monotonous increase of both efficiency and output power is characterized by a steep grow when the secondary-emission yield is slightly greater than some threshold value, and can be saturated when the secondary-emission yield essentially exceeds the threshold value.

The threshold value of the secondary-emission yield needed for generation of periodical oscillations depends both on the cavity Q-factor, and on the mode of oscillations.

When the threshold value is essentially lower than the secondary-emission coefficient of platinum, it is possible to simplify the manufacturing by making the cold cathode of pure inexpensive metal, like copper or molybdenum, rather than plating it with platinum. The resulting decrease of the efficiency and the output power can be small enough to justify lower manufacturing costs.

REFERENCES

1. J.R.M. Vaughan. An Experimental Cold Cathode Magnetron // *Le Vide.* 1956, №65, p.251-257.
2. S.V. Gritsaenko, V.D. Yeryomka, M.A. Kopot'. Et al. Multicavity cold secondary-emission cathode magnetron: Achievements, problems, prospects. // *Radiofizika i Electronika*. 2005, v.10, p.499-529.
3. K. Schünemann, S.V. Sosnytskiy, D.M. Vavriv. Self-Consistent Simulation of the Spatial-Harmonic Magnetron with Cold Secondary-Emission Cathode // *IEEE Trans. on Electron Devices.* 2001, v.48, p.993-998.
4. I.M. Bronstein, B.S. Freiman. *Secondary electron emission*. M.:"Science", 1969.
5. J.R.M. Vaughan. A New Formula for Secondary Emission Yield // *IEEE Trans. on Electron Device.,* 1989, v.36, p. 1963-1967.
6. A. Shih, C. Hor. Secondary Emission Properties as a function of the Electron Incidence Angle // *IEEE Trans. on Electron Devices*. 1993, v.40, p.824-829.

ЗАВИСИМОСТЬ ХАРАКТЕРИСТИК МАГНЕТРОНА ОТ КОЭФФИЦИЕНТА ВТОРИЧНОЙ ЭМИССИИ ХОЛОДНОГО КАТОДА

Н.И. Автомонов, С.В. Сосницкий, Д.М. Ваврив

Численное моделирование магнетронов мм-длин волн с холодными вторично-эмиссионными катодами показывает, что такие важные практические характеристики как выходная мощность, эффективность, рабочий ток зависят от вторично-эмиссионных свойств холодного катода, используемого в таких магнетронах. Однако, в некоторых случаях усиление магнетронных характеристик может достигаться с относительно низкими коэффициентами вторичной эмиссии холодного катода. Это открывает путь для использования чистых недорогих металлов для изготовления катода. Соотношение между коэффициентом вторичной эмиссии и характеристиками магнетрона исследовано для реализации указанного подхода.

ЗАЛЕЖНІСТЬ ХАРАКТЕРИСТИК МАГНЕТРОНУ ВІД КОЕФІЦІЄНТУ ВТОРИННОЇ ЕМІСІЇ ХОЛОДНОГО КАТОДУ

М.І. Автомонов, С.В. Сосницький, Д.М. Ваврів

Чисельне моделювання магнетронів мм-довжин хвиль з холодними вторинно-емісійними катодами показує, що такі важливі практичні характеристики як вихідна потужність, ефективність, робочий струм залежать від вторинно-емісійних властивостей холодного катоду, який використовується у таких магнетронах. Але, в деяких випадках підсилення магнетронних характеристик може досягатись з відносно низькими коефіцієнтами вторинної емісії холодного катоду. Це відкриває шлях для використання чистих некоштовних металів для виготовлення катоду. Співвідношення між коефіцієнтом вторинної емісії та характеристиками магнетрону досліджене для реалізації вказаного підходу.