Theoretical Analysis of Low Vacuum Microwave Discharge Exciting and Maintaining Conditions in Resonator Type Plasmatron

Madveika S.I.[1], Bordusau S.V.[1]

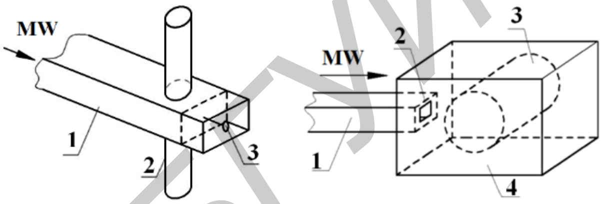
[1]*Belarusian State University of Informatics and Radioelectronics, P.Brovki, 6, 220013,Minsk, Belarus, e-mail: bordusov@bsuir.by*

The efficiency of a cavity microwave resonator using for getting large volume (more than 4000 cm^3) low vacuum plasma for group treatment of products in the microelectronics technology has been evaluated. The results showed that the value of electric field breakdown intensity about $E_0 \approx 200$ V/cm in a resonator system for low vacuum can be already achieved at a microwave power higher than 50 W. The conditions of preserving resonating properties at exciting plasma with a volume of 9000 cm^3 in resonator and in case of placing a various number of silicon wafers in the microwave discharge have been analyzed.

Keywords: microwave plasma, resonator, waveguide

1 INTRODUCTION

The use of high volume (more than 4000 cm^3) low pressure plasma is more advantageous in comparison with low volume plasma as it provides the opportunity to treat microelectronic devices in groups and the controllable treatment of silicon wafers of big sizes (200 and 300 mm in diameter). Because of this the analysis of the ways of exciting and maintaining microwave (MW) discharge in the discharge chamber, the side linear dimensions of which are bigger than the length of electromagnetic waves of a MW range, is of scientific as well as practical interest and significance 0.



a) b)

1 – waveguide; 2 – quartz tube; 3 – trimming piston

1 – waveguide; 2 – slot for entering electromagnetic energy; 3 – quartz tube; 4 – resonator

Fig.1: MW applicators used in MW plasmatron constructions

2 THEORETICAL ANALYSIS

In order to excite plasma in a limited space, it is necessary to concentrate MW energy up to the level of intensity of the electrical component of electromagnetic field E_{br}, close to the breakdown value (for medium vacuum discharges the value E_{br} equals to 80 –300 V/cm 0, 0).

Let's perform a comparative evaluation of the electrical component of the electromagnetic field for a standing wave in a MW non resonator type applicator (waveguide construction (Fig.1, *a*) and a MW resonator type applicator (a rectangular resonator (Fig.1, *b*), often used in MW plasmatron constructions.

In order to calculate the meansquare value of electric field intensity E_0 in the quartz tube placed in the waveguide as the function of MW power P_{inc}, we use the equation 0:

$$E_0 = \sqrt{\frac{P_{inc}}{0,662 \cdot 10^{-3} ab \left(\frac{\lambda}{\lambda_B} \right)}}, \qquad (1)$$

where P_{inc} – the value of the power applied to the waveguide;

a,b – the size of the wide and narrow walls of the waveguide respectively;

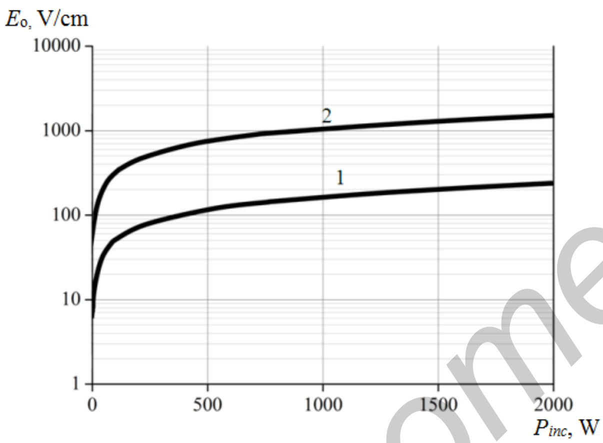
λ – wavelength in the open space;

λ_B – wavelength in the waveguide.

Meansquare intensity of the electric field E_0 of a non loaded resonator for the same type of oscillations can be calculated according to formula 0:

$$E_0 = \sqrt{\frac{Q_0 P_{inc}}{\omega \cdot \varepsilon_0 \cdot V_c}} \ , \qquad (2)$$

where Q_0 – non loaded resonator quality factor;
P_{inc} – the value of the power applied to resonator;
ω – field circular frequency;
ε_0 – electric invariable of the vacuum;
V_c – resonator's volume.
The results of the calculations of electric field intensity dependency on the power P_{inc} of electromagnetic wave in the waveguide with the cross section 45x90 mm^2 and in the resonator's cavity with the quality factor $Q \approx 10000$ (the average value of quality factor 0, characteristic for an empty cavity resonator (CR) used in MW heating devices), are presented in Fig. 2.



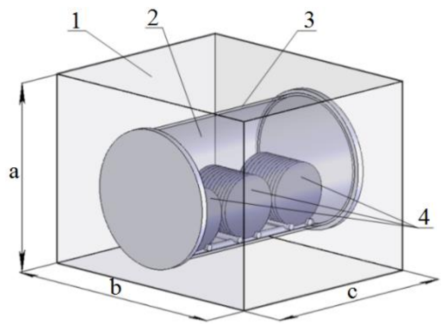
1 – coherent non resonant type system (waveguide); 2 – resonator

Fig.2: Calculated meansquare values of electric component E_0 of MW electromagnetic field intensity in the power range for waveguide and resonator

The analysis of the graphs presented on Fig. 2 shows that in order to obtain the electromagnetic field intensity higher than 200 V/cm in the waveguide we need a MW power of at least 2000 W. In the resonator the same value of the electric field intensity E_0 is already achieved at a MW power higher than 50 W. Because of this in order to excite and maintain a MW discharge of high volume in plasmatrons it is better to use a MW resonator type applicator.
During technological processes of a group plasmachemical treatment of microelectronic materials the reaction – discharge chamber (RDC) of the MW plasmatron is loaded with a certain number of semiconductor wafers (Si, Ge) having a high value of the dielectric losses slope ratio. In this case the increase of volume taken by semiconductor wafers in the RDC may lead to a CR quality factor change 0. Because of this, the analysis of a CR quality factor change with plasma in accordance with the quantity and the material of the object to be treated in it is of interest.
Total quality factor (loaded) Q of a CR may be considered as a superposition of quality factors 0, 0:

$$\frac{1}{Q} = \frac{1}{Q_{met}} + \frac{1}{Q_m} + \frac{1}{Q_\Sigma} \qquad (3)$$

where Q_{met} – intrinsic quality factor of a CR determined by the losses in the walls;
Q_m – quality factor determined by the filling medium;
Q_Σ – quality factor determined by the elements of connection with external devices.
It is assumed that in the appropriately made closed resonator the MW energy does not escape into the external environment and is completely concentrated in the resonator's cavity, that is why the latter component in the equation (3) is close to 0 and can be neglected.
Let's evaluate the quality factor Q of a CR of prismatic form with sides a, b, c with a cylindrical quartz tube inside having a diameter d and a length h equal to resonator's depth *($h = c$)*, within which the MW discharge is formed (Fig.3).



1 – cavity resonator; 2 – discharge chamber; 3 – quartz tube; 4 – silicon wafers

Fig.3: Schematic picture of the position of a quartz tube with plasma and silicon wafers in prismatic resonator with regard to the calculation of loaded resonator quality factor

In RDC there are wafers from semiconductor material – monocrystaline silicon. Non uniformity inside the cavity resonator, characteristic for the process of plasma-chemical treatment, shall be considered as media having dielectric properties with losses 0, 0.

Quartz glass with dielectric loss slope ratio equal to 0,0025 - 0,0006, from which the RDC is made, is practically transparent for MW radiation that is why its influence on the resultant quality factor of the loaded resonator 0 will not be taken into account. Hence, the equation characterizing the total quality factor *Q* of CR can be presented in the following way:

$$\frac{1}{Q} = \frac{1}{Q_{met}} + \frac{1}{Q_{pl}} + \frac{1}{Q_s} \qquad (4)$$

where Q_{pl} – quality factor of the CR partially filled with plasma;

Q_s – quality factor of the CR determined by its being partially loaded with semiconductor wafers.

We believe that the CR works in a multimode regime at simultaneous excitation of a few types of oscillations 0, 0. The structure of the field in the resonator with losses and without them is the same 0. In this case intrinsic quality factor of the rectangular CR (non loaded) is defined according to the formula 0:

$$Q_{met} = \frac{2}{\delta \cdot \mu} \cdot \frac{V}{S} \qquad (5)$$

where $\delta = \sqrt{c / 2\omega_r \cdot \sigma \cdot \mu_a}$ - depth of field penetration into the metal;

$c = 3 \cdot 10^8$ m/c – light speed;

$\omega_r = 2\pi f_r$ – resonant frequency (f_r=2,45 GHz);

σ – specific conductivity of the CR’s walls;

μ_a – absolute magnetic penetrability of the CR walls’ material;

$\mu = \mu_a/\mu_0$ – relative magnetic penetrability of the CR walls’ material;

μ_0 – magnetic invariable;

V – volume of the CR;

S – CR’s surface area.

Quality factor Q_{pl} determined by partial filling of the resonator with plasma may be defined with ratio 0:

$$Q_{pt} = \frac{\varepsilon \cdot \omega_{pl}}{4\pi \cdot \sigma_{pl}} \qquad (6)$$

where ε – plasma dielectric penetrability;

σ_{pl} – plasma conductivity;

ω_{pl} – plasma frequency.

Quality factor Q_s determined by loading cavity resonator with semiconductor wafers can be calculated with formula 0:

$$Q_s = 2\pi f_r \frac{W}{P_s} \qquad (7)$$

where *W* – energy stored in the oscillatory system;

P_s – power losses in semiconductor wafers.

The process of wafers warming during their interaction with a MW field will be similar to a usual dielectric warming up. The power losses in this case are defined with expression 0:

$$P_s = 2\pi f E^2 \varepsilon_0 \varepsilon_s' tg\delta \qquad (8)$$

where *f* – frequency of electromagnetic field;

E – intensity of electric field;

ε'_s – relative dielectric penetrability of semiconductor wafers;

*tg*δ – dielectric losses slope ratio (for silicon wafers *tg*δ = 0,15 0).

Fig. 4 shows calculated dependency of total quality factor *Q* of a CR loaded with plasma and silicon wafers on the number of silicon wafers 100 mm in diameter and 0,33 mm thick.

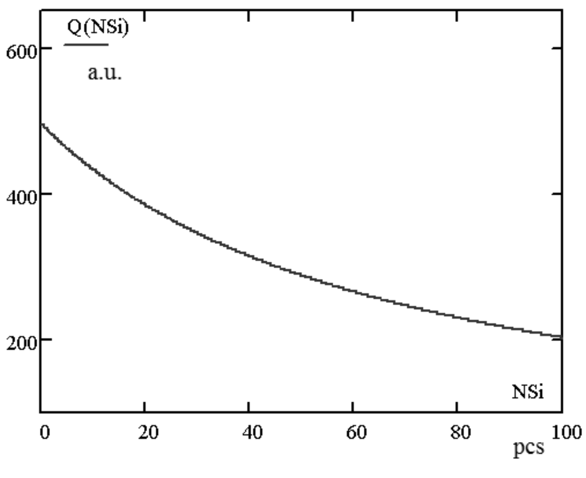


Fig.4: Dependence of total quality factor of the cavity resonator partially filled with plasma Q on the number of silicon wafers loaded into it

The results of the calculations show that the increase in the number of wafers in the CR from 1 to 100 pcs leads to the change of total quality factor *Q* of the loaded resonator from 500 to 200.

The evaluation of quality factor of the CR with respect to the conditions of technological application shows that if a medium power ($P_{gen} \approx$ 650 W) MW magnetron is used as a source of electromagnetic waves the intensity of the electric field E_0 in the resonator at total quality factor $Q \approx 200$ will be not less than 200 V/cm. This value is sufficient for exciting MW discharge in a resonator type plasmatron 0.

3 CONCLUSIONS

It is shown that for a MW plasmatron in case of a appropriately calculated and made resonator, much higher values of the meansquare intensity of the electric field E_0 (approximately 10 times) in comparison with the non resonator type applicator can be observed in the plasma forming area. The obtained calculated data give the estimation of the MW power value necessary for exiting a MW medium vacuum discharge in a resonator type plasmatron.

Acknowledgements

This research has been supported by the State Program of scientific researches "Functional and composite materials, nanomaterials", assignment № 4.5.02.

REFERENCES

[1] Bordusov S V, Microwave plasma technologies in the production of electronic devices, Minsk: Bestprint, 2002.

[2] Mak-Donald A, Microwave breakdown in gases, M.: Mir, 1969.

[3] Mik D, Electrical breakdown in gases, M.: Publishing House of Foreign Literature, 1960. – 605 p.

[4] MW-energy, (Ed. E Okress). In 3 V., M.: Mir, 1971. – V. 1.

[5] Shirman Y D, Radio waveguides and cavity resonators, M.: Svyaz'izdat, 1959.

[6] Brandt A A, Investigation of dielectrics at microwave frequencies, M.: Fizmatlit, 1963.

[7] Harvey A F, Technics microwave frequencies, M.: Soviet radio, 1965.

[8] Samoylik S S et al., The Q-factor of a rectangular cavity with a variable number of dielectric inhomogeneities, Radio electronics. Informatics. Management. –2008. –№1. –P.32–37.

[9] Ginzburg V L, The propagation of electromagnetic waves in a plasma, M.: Fizmatisdat, 1960.

[10] Element properties: reference book: in 2 P., edited by G.V. Samsonova. – M.: Metallurgy, 1976. – P. 1.

[11] MW-energy, (Ed. E Okress). In 3 V., M.: Mir, 1971. – V. 2.

[12] Tareev B M, Physics of dielectric materials, M.: Energoizdat, 1982.