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Research of Dynamic Processes in the Resistance Evaporator

L. Šumskienė, V. Sinkevičius
Department of Electrical Engineering, KTU Panevezys Institute,
S. Daukanto str. 12, 35212 Panevezys, Lithuania; phone:+370 45 434247, e–mail: lina.sumskiene@ktu.lt,
vytenis@elekta.lt.

Introduction

Dynamics of the electrons and ions flow to the substrate, on which nanostructures are produced using thermal evaporators, has a great importance to the formation of such derivatives. Charges, depositing on the substrate, can give us an information about the stage of these derivatives [1,2]. Temperature distribution of the evaporator, which is mostly of sophisticated configuration, determines the flow of charges in the vacuum system. Unfortunately there are no analytical methods to determine the temperature distribution of such configurations and finite element models are usually simplified [3]. The alternating voltage is used for the heating of the evaporator. Therefore the aim of this work was to identify the influence of the alternating voltage on the dynamical processes of the evaporator temperature. The results will allow us to understand, how the alternation of the emission current depends on the alternating voltage and to take these alternations to account in the control system of condensation process.

Model of resistance evaporator

The tungsten coil evaporator is used in the vacuum evaporation system. Its real construction is fairly sophisticated. Therefore the construction of two wired cylinders was changed by one equivalent cylinder creating the model of coil evaporator for the simplification of the task [3]. The fragment of the real coil evaporator geometry and the created model of evaporator geometry are shown in Fig. 1.

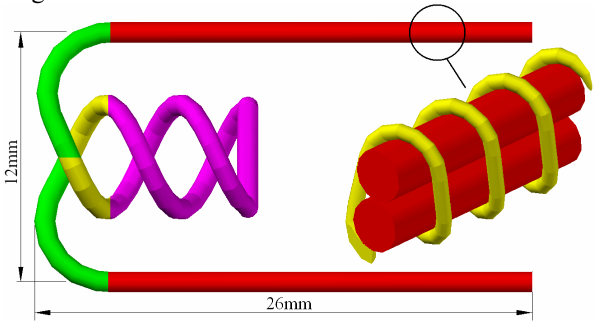

Fig. 1. Geometry of resistance evaporator

The ambience of the evaporator is the vacuum and in high vacuum the main way of the energy transfer is the radiation. The best decision is to use FEM, employing the radiation matrix method for more generalized radiation problems involving two or more surfaces. Extending the Stefan-Boltzmann Law for a system of N enclosures, the energy balance for each surface in the enclosure for a gray diffuse body is given by Siegal and Howell, which relates the energy losses to the surface temperatures [4]:

$$\sum_{i=1}^{N}\left(\frac{\delta_{ji}}{\varepsilon_{s,i}}-F_{ji}\frac{1-\varepsilon_{s,i}}{\varepsilon_{s,i}}\right)\frac{1}{S_i}Q_i=\sum_{i=1}^{N}\left(\delta_{ji}-F_{ji}\right)\sigma_B T_i^4\;; \quad (1)$$

where N – number of radiating surfaces, δ_{ji} – Kronecker delta $\delta_{ji}\equiv\begin{cases}0, \text{ if } i\neq j;\\ 1, \text{ if } i=j.\end{cases}$, $\varepsilon_{s,i}$ – effective emissivity of surface i, S_i – area of surface i, Q_i – energy loss of surface i, T_i – absolute temperature of surface i, F_{ji} – radiation view factors, σ_B – Stefan-Boltzmann constant.

In the radiation matrix method, for a system of two radiating surfaces i and j, can be expanded as:

$$Q_{ij}=K'\left(T_i-T_j\right); \quad (2)$$

where $K'=S_i\varepsilon_{s,i}F_{ij}\sigma_B\left(T_i^2+T_j^2\right)\left(T_i+T_j\right)$. K' cannot be calculated directly since it is a function of the unknowns T_i and T_j. The temperatures from previous iterations are used to calculate K' and the solution is computed iteratively. For more general case, when the model is created of more than two surfaces, the equation (1) can be used construct a single row in the following matrix equation:

$$\{\mathbf{Q}\}=[\mathbf{K_t}]\{\mathbf{T}^4\}, \quad (3)$$

or

$$\{\mathbf{Q}\}=[\mathbf{K}']\{\Delta\mathbf{T}\}, \quad (4)$$

where $[\mathbf{K_t}]$ – thermal conductivity matrix, which is created using equation (1). The radiation is included to the solution of temperature distribution problem by superimposing surfaces of radiating bodies with a mesh of surface effect elements and defining the space node, which simply is a node that absorbs radiant energy not received by other surfaces in the model. Than the radiation matrix is generated using the nodes of surface effect elements and a space node. The thermal conductivity matrix $[\mathbf{K_t}]$ is created during the generation of radiation matrix and the view factors are calculated too. After that this radiation matrix is read in as a superelement for the calculation of $[\mathbf{K}']$ matrix and for the solution of temperature distribution using equation (4). In such a way created matrix relates the surfaces of all the objects of the model exchanging the radiant energy and also absorbs the energy eradiated into the space. These flows of energy are used for the calculation of the temperature distribution of evaporator.

The evaporator supplied with alternating voltage and the current flow heats it. Therefore the temperature distribution of evaporator will be estimated solving the thermo-electrical problem with radiation using the tool, which implements this method (ANSYS). The thermo-electrical element *Solid69* and the surface effect element *Shell57* were chosen for the creation of the finite element model.

The radiation matrix method is limited by the maximum number of the surface elements. But in our case it is more important to know the temperature distribution in the area of the coil. Therefore the mesh step in the area of evaporator coil was smaller then in the other parts of the evaporator. The potential difference was applied on the ends of the evaporator (Fig. 2) and the calculation where done.

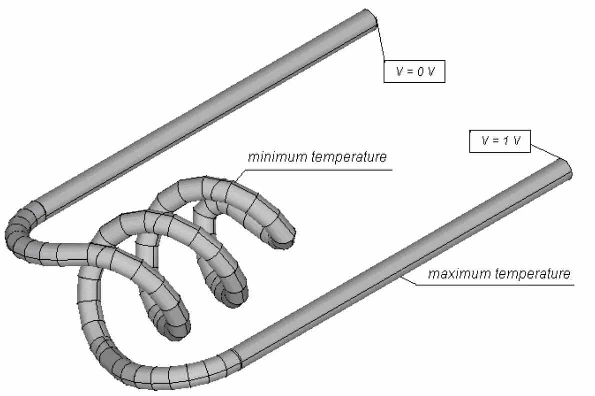

Fig. 2. Model of evaporator without clamps

Unfortunately the results of calculated temperature distribution showed that the created model of evaporator wasn't correct. The highest temperature had to be in the area of the coil, but in this case it was the lowest there (Fig. 2). That had happened because the temperature of the evaporator ends wasn't taken into account. In the real evaporation system the evaporator is fixed in the clamps, which ends are cooled by water and temperature is low there. Therefore the model of the evaporator was improved and its ends were fixed in the copper clamps. In comparison with measurement of the evaporator the clamps are very large (4.5x9x16 mm). Therefore the equivalent clamps were drawn undersized four times (1.25x2.25x4 mm). The equivalence was obtained changing the material properties of copper – the thermal conductivity and the density were raised four time. The uniform 20°C temperature was set on the ends of the clamps. After the calculation the results of the temperature distribution were as we expected – the temperature of the coil was the highest and the temperature of the evaporator's part near the clamps was lowest (Fig. 3).

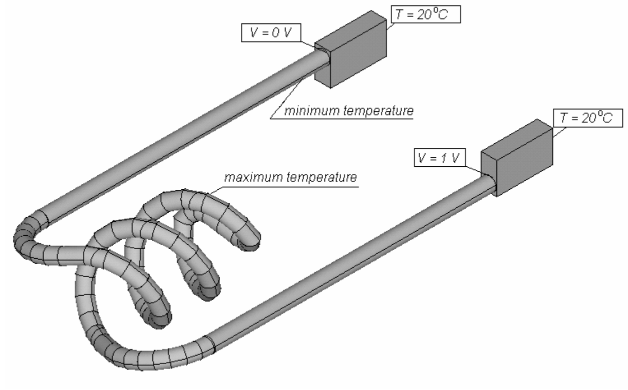

Fig.3. Model of evaporator with clamps

Using the current model the calculations were performed alternating the voltage of the ends of the evaporator U_g from 0.5 V to 6V. The maximum T_{max} and the medium T_{mid} temperature were fixed. The created finite element model of the evaporator was proved by doing the experiment. The temperature of evaporator T_m was measured alternating the voltage of the evaporator. The platinum thermocouple (Type B) was used for the temperature measurement. The measuring limits of such thermocouple are form 100°C to 1700°C. The results of the calculation and measurements are shown in Figure 4. As we can see, the measured values are very close to the calculated results. Therefore the created finite element model of the evaporator can be used for the research of the temperature dynamical processes of the evaporator.

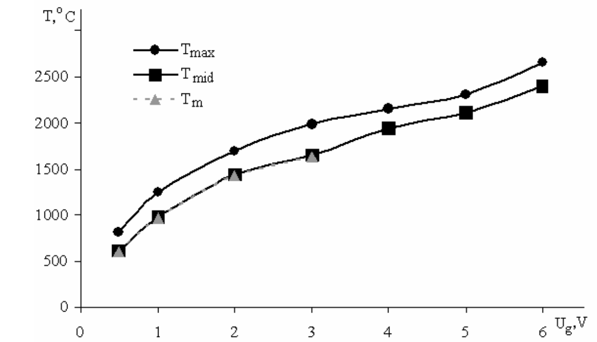

Fig. 4. Calculated and experimental results of evaporator temperature

Research of temperature dynamical processes

During the experiment the evaporator is heated gently raising the voltage. Therefore in the model the voltage was applied to the evaporator in four stages. First of all we applied the voltage of 1.5 V to the ends of evaporator and kept hold it for 10 s. After the heating of the evaporator, the voltage was raised to 3 V for 5 s. Then it was raised to 4.5 V also for 5 s, and after that – to 6.22 V for 5 s. In such a way the curve of the temperature dynamics was found (Fig. 5).

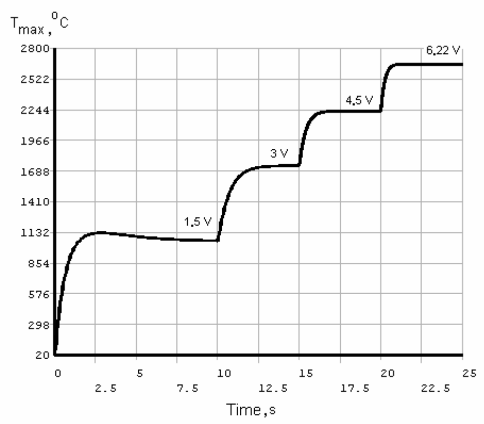

Fig. 5. The transient process of evaporator temperature

Next the calculated curve of the transient process is shown in parts (Fig. 6 – Fig. 9) for full analysis.

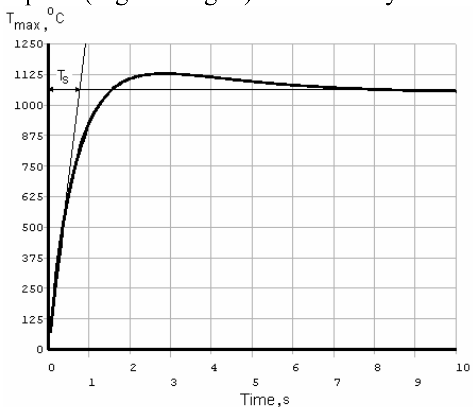

Fig. 6. The transient process of evaporator temperature, when the voltage of evaporator is 1.5 V

The evaporator heated up to 1250°C temperature during the course of 3 s (Fig. 6). The time constant of this transient process is $T_s = 0.78$ s. But later the temperature of the point of the maximum temperature began to drop (Fig. 6). It was happened, because the temperature distribution of the evaporator regrouped and the point of the maximum temperature changed its place during the heating process of the evaporator.

The transient process of the evaporator temperature has elongated raising the voltage twice. But the temperature of the evaporator rose only in 460°C (Fig. 7). The 1710°C temperature set in during the course of 3.5 s and the time constant of this transient process was T_s = 0.9s.

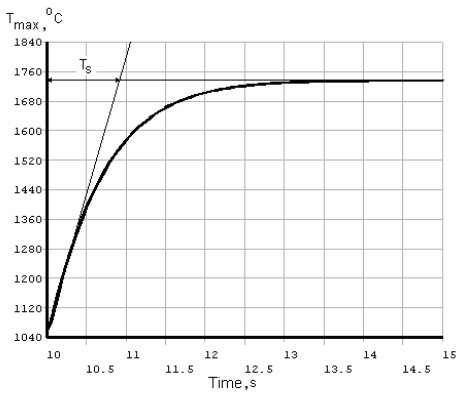

Fig. 7. The transient process of evaporator temperature, when the voltage of evaporator is 3 V

Looking at the Figure 8, the temperature rose to 2224°C applying the voltage of 4.5 V to ends of the evaporator. This temperature set in during the course of 3 s and the time constant of this transient process was T_s = 0.45 s.

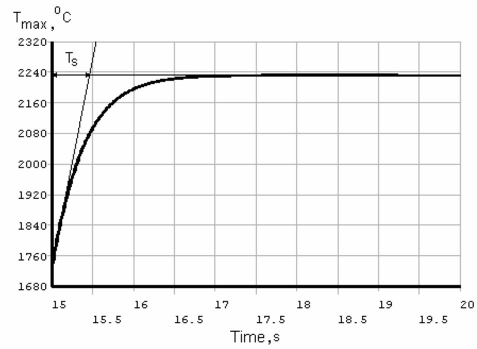

Fig. 8. The transient process of evaporator temperature, when the voltage of evaporator is 4.5 V

The temperature reached 2656°C, when we applied the last voltage jump of 6.22 V (Fig. 9). This temperature set in very quickly – during the 1.5 s and the time constant of this transient process was $T_s = 0.3$ s. Accordingly to the results, we can affirm, that the dynamics of the evaporator temperature depends not only on the applied voltage, but also on the initial temperature of the evaporator.

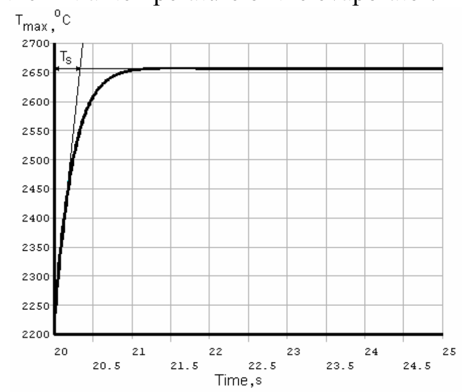

Fig. 9. The transient process of evaporator temperature, when the voltage of evaporator is 6.22 V

Influence of alternating voltage on temperature of evaporator

The evaporator was heated applying the jumps of the voltage, which were equal to the value of the effective voltage. But really the voltage of the 50 Hz frequency is applied to the evaporator and the alternation of this voltage has an influence on the process of the evaporator heating. For the analysis of these processes, the voltage alternating every 5 ms was applied to the ends of evaporator. So we the voltage of 8.8 V was kept during the one half period and the voltage of 0 V – during the other half period. As shown in the Fig. 10, the evaporator is cooling and the temperature is oscillating under the influence of the alternating voltage. The temperature of the evaporator dropped to the value of 2238°C during the course of 1.5 s. The temperature oscillates with amplitude of 7°C, when the process becomes steady. The transient process of the temperature drop is shown in Fig. 11.

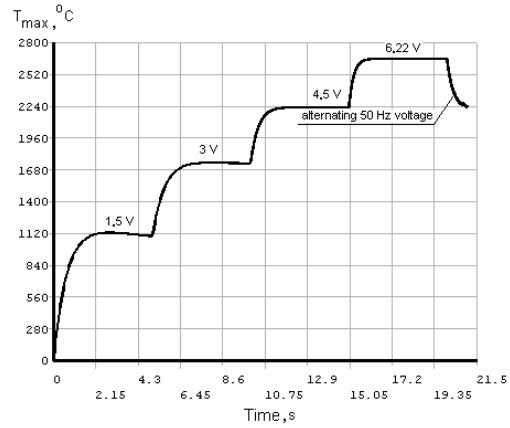

Fig. 10. The transient process of evaporator temperature

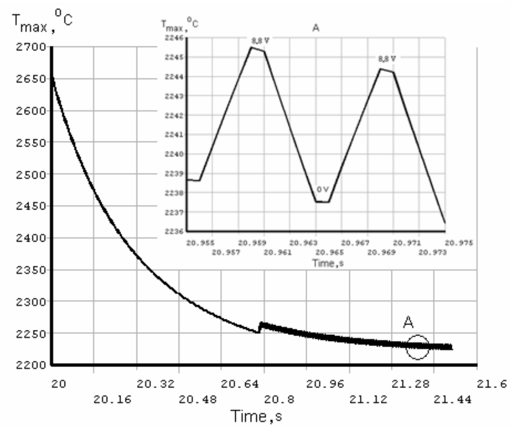

Fig. 11. The transient process of evaporator temperature depending on alternating 50 Hz voltage

Conclusions

The calculations of the transient processes of the evaporator temperature were done. They allowed us to determine the time constant of these processes, which is alternating between 0.3 s and 0.9 s depending on the applied voltage and initial temperature of evaporator. Therefore the control system of evaporator temperature must to restart the control actions every 30 ms.

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The aim of this work was to explore the influence of the alternating voltage on the dynamical processes of the evaporator temperature. Temperature distribution of the evaporator, which is mostly of sophisticated configuration, determines the flow of charges in the vacuum system. Therefore FEM was choused for the calculation of the temperature distribution and dynamical processes of the evaporator temperature. The calculations allowed us to determine the time constant of these processes, which is alternating between 0.3 s and 0.9 s depending on the applied voltage and initial temperature of evaporator. Therefore the control system of evaporator temperature must to restart the control actions every 30 ms. Ill. 11, bibl. 4 (in English; summaries in English, Russian and Lithuanian).

Л. Шумскене, В. Синкявичюс. Исследование динамических процессов резистивного испарителя // Электроника и электротехника. – Каунас: Технология, 2008 – № 6(86). – С. 7–10.

Цель работы – исследование динамических зависимостей температуры вольфрамного спиралеобразного испарителя от величины питающего переменного напряжения. Поток зарядов в вакуумной системе определяется распределением температуры на поверхности испарителя, которая имеет сложную пространственную конструкцию. Поэтому для расчёта распределения температуры на поверхности испарителя был выбран метод конечных элементов. При расчёте переходных процессов нагревания испарителя определено, что постоянная времени реакции испарителя на изменение напряжения питания колеблется в пределах от 0,3 с до 0,9 с, в зависимости от величины подаваемого напряжения и начальной температуры испарителя. Поэтому система управления температурой испарителя должна быть способна обновлять управляющее воздействие не реже как через 30 мс. Установлено, что при переходе на переменное напряжение питания 50 Гц температура испарителя уменьшается на 432 °C, а после переходного процесса максимальная температура испарителя колеблется с амплитудой в 7 °C. Ил. 11, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

L. Šumskienė V. Sinkevičius. Varžinio garintuvo dinaminių procesų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008 – Nr. 6(86). – P. 7–10.

Darbo tikslas – ištirti volframinio spiralinio garintuvo temperatūros dinaminių procesų priklausomybę nuo jam tiekiamos kintamosios įtampos. Vakuuminėje sistemoje krūvių srautą lemia temperatūros pasiskirstymas garintuvo paviršiuje, kuris dažniausiai būna sudėtingos erdvinės konfigūracijos. Todėl temperatūros pasiskirstymui garintuvo paviršiuje apskaičiuoti buvo pasirinktas baigtinių elementų metodas. Apskaičiavus garintuvo įšilimo pereinamuosius procesus, nustatyta, kad garintuvo reakcijos į kaitinimo įtampą laiko pastovioji svyruoja nuo 0,3 s iki 0,9 s, priklausomai nuo pateiktos įtampos šuolio ir pradinės garintuvo temperatūros. Todėl garintuvo temperatūros valdymo sistema turi gebėti atnaujinti valdymo poveikius ne rečiau kaip kas 30 ms. Nustatyta, kad garintuvui tiekiant 50 Hz dažnio kintamąją įtampą, jo temperatūra sumažėja 432 °C, o pereinamajam procesui nusistovėjus, maksimali garintuvo temperatūra svyruoja 7 °C amplitude. Il. 11, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).