Method of magnetron target temperature evaluation by analysis of thermal radiation spectrum

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Abstract. A method of vacuum chamber magnetron target temperature evaluation by measurement of aggregated spectrum of gas discharge emission and target thermal radiation is proposed. Method is based on matching of calculated black body radiation spectrum with given temperature and the minimal points on the measured spectrum.

In the few last years has greatly increased interest in the study of high-power metal targets magnetron sputtering process [1–3]. One of the main factors of high-power sputtering process is the considerable heating of target up to very high temperatures. It is very important to have a reliable instrument for target temperature measurement right during the sputtering process. Direct measurement by means of contact sensor is difficult because of fast temperature destruction of such sensors. Traditional contactless pyrometric methods give a significant measurement error due to the hot target sputtering process output optical radiation is the result of two different processes – a gas discharge light emission and the target thermal radiation. Object temperature measurement by means of optical spectrum processing (spectrum pyrometry) now is well known [4, 5] and became more popular due to cost reduction and availability of compact spectrometer devices. A main trouble of using spectrum pyrometry for hot magnetron target temperature measurements is the big quantity of intensive emission spectral lines in the input spectrum that makes the task of thermal radiation spectrum segregation a rather complex (figure 1). A given article describes a method of spectrum measurements processing for target temperature evaluation.

The experiments were performed at the modernized setup UVN-71 equipped with 78 dm³ vacuum chamber and flat magnetron. A target was made of round tantalum sheet with a diameter of 70 mm and thickness of 0.5 mm. To provide a hot target mode, the tantalum target was fixed with gap of 1 mm to the metal plate, cooled by flowing water. A target sputtering was performed with the residual pressure of 10⁻² mTorr, argon pressure of 3.5 mTorr and discharge current density from 8 to 36 mA/cm².

For the spectrum measurement a compact spectrometer device ISM3600 was used [6, 7]. ISM3600 is capable for optical spectrum measurement in region 250–1000 nm with the resolution in visible area not worse than 2.5 nm and absolute wavelength measurement error not greater than ±0.5 nm. The optical signal output from vacuum chamber is provided by quartz monofiber with diameter of 0.4 mm. ISM3600 software has a database with periodic table elements spectral lines that allows detecting the elemental and ionic composition of gas discharge during the magnetron sputtering.
Temperature calculation method is based on separation of target thermal radiation spectrum from the total light spectrum gathered from the chamber. The separation is performed in few stages:

- depending on the number of emission spectral lines, a viewing window be defined; the smaller the lines number, the wider the viewing window and vice versa. For most of the plasma emission spectra, the window size is approximately of 30 nm;
- inside the first viewing window, at begin of spectral data, a minimum value (minimum signal level) be sought and stored it in the buffer. Then algorithm switches to the next viewing window and repeats the operation along the all spectral data, received from the spectrometer device;
- using the array of minimums obtained at the previous step, a thermal radiation spectrum being constructed by third-degree polynomial approximation.

The source unfiltered data and the resulting spectrum obtained for experiment with discharge power density 14.8 W/cm$^2$ are shown on figure 2.

For target’s temperature evaluation a spectrum of black body radiation with average operational temperature in the given spectrum range is being calculated. A calculation of spectral intensity is processed by well-known Planck’s formula:

$$I(\lambda) = \frac{2\pi hc^2}{\lambda^5 \left( e^{hc/\lambda kT} - 1 \right)},$$

where $I(\lambda)$ – spectral intensity at the given wavelength $\lambda$; $h$ – Plank’s constant; $k$ – Bolzman’s constant; $T$ – object’s temperature (K); $c$ – light speed in vacuum.

The calculated intensity $I(\lambda)$ is normalized to the value of the measured thermal radiation intensity at a fixed wavelength of 850 nm, and then the integral difference between the two spectra – theoretically for a selected temperature, and segregated from the real spectrum is computed. Such difference is calculated only for the signal ranges where intensity is not less than preset threshold (for example, 5 % from the maximum). Then calculations are repeated for other temperatures and after few iterations (using, for example, a bisection method), it is possible to find a temperature value where the integral difference is minimal.

Example is shown on figure 3: a spectrum data are obtained from target, heated to 1680 K with discharge power density 14.8 W/cm$^2$; curve $I$ corresponds to black body radiation spectrum with $T = 1680$ K. A deviation from this temperature to, for example, ±20 K gives significantly bigger integral difference (curves 2 and 3 on figure 3).

A set of experiments with different discharge power density were performed and target’s temperatures were evaluated. The results show a linear dependence between power and temperature (figure 4) that corresponds to target heating process.
Figure 3. Calculation of black body radiation spectrum.

One of given method obvious disadvantage is impossibility of thermal radiation accurate segregation due to errors in signal minimums detection caused by the optical sensor noise. This can be compensated by applying a various algorithms of signal smoothing.

References

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