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ON THE LIFE EXPECTANCY OT HIGH-POWER CW MAGNETRONS FOR SUPERCONDUCTING ACCELRATORS

Modern CW or pulsed Superconducting RF (SRF) accelerators require efficient RF sources controllable in phase and power with a reduced cost of RF power per Watt. Utilization of the high-power CW magnetrons as RF sources in SRF accelerators was proposed in a number of works. But, the CW magnetrons are designed and optimized as RF sources for industrial heating, and the lifetime of the tubes is not the first priority as it is required for high-energy accelerators. The high-power industrial CW magnetrons use the cathodes made of pure tungsten. The emission properties of the tungsten cathodes are not deteriorated much by electron and ion bombardments, but the latter causes sputtering of the cathode in the magnetron crossed fields. The sputtered cathode material covers the magnetron interior. That lead to sparks and discharges limiting magnetrons lifetime. We considered an analysis of magnetron failure modes vs. output power, developed a model of ionization of the residual gas in the magnetrons interaction space and simulated the spattering of the cathode in 100 kW CW magnetrons to estimate the life expectancy. Basing on results we proposed ways to increase the CW magnetrons longevity for SRF accelerators.

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We considered an analysis of initially developed by Burley Industries Inc. CW, 915 MHz, high-power, 10 vanes magnetrons with strapped resonant system vs. failures at output power levels of 30, 50 and 75 kW [1]. For 30 kW CW magnetrons with anode voltage of 12.6 kV, anode current of 2.8 A and the cathode filament power of 1.14 kW the average time in the field for new 30 kW tubes was 119 months, [1], i.e., $\sim 20 \cdot 10^3$ hours. For 50 kW tubes at the anode voltage of 15 kV, anode current of 4 A at the filament cathode power of ≈1 kW and increased magnetic field it was $\sim 5 \cdot 10^3$ hours. The majority of failures of these tubes were caused by internal arcing. For 75 kW tubes at the anode voltage of 17.5 kV at the anode current of 5.1 A at the cathode filament power of 1.54 kW and additionally increased magnetic field the life time was less. It was noted that the internal arcing was considerably greater in tubes at the output power of 60 kW and more [1].

Thus, an increase of the CW magnetrons anode voltage and current reduces the tubes life time due to internal arcing and discharges.

We analysed impact of ionization of the residual gas in vicinity of the cathode considering impact of motion of electrons at operation of high-power CW magnetrons on the tubes life time with a simple model of ionization of the residual gas in a magnetron vacuum system. Typical current density of tungsten cathodes is about of 0.3 A/cm^2 [2]. That requires the cathode temperature of about 2500 K. An operation of the cathode at such high temperature and the cathode additional overheat caused by electron back-stream worsen the vacuum in the cathode vicinity approximately by an order of magnitude. If in a cold magnetron the vacuum pressure is typically $\leq 10^{-6}$ torr, during tube operation the average vacuum pressure in the interaction space is increased to $\sim 5 \cdot 10^{-6}$ torr or more.

In the interaction space of operating magnetron, Larmor electrons move along trochoids during few cyclotron periods alternately approaching the cathode and anode. For 100 kW commercial e.g., type CWM-100L CW magnetron operating at the magnetic field of 0.238 T [2], the anode voltage is ≈22 kV. At these parameters, the electron energy on the cyclotron orbits (closer to the cathode) varies from approximately 0 to 10 keV for each trochoid period. The radius of the cyclotron orbit is ≈ 0.21 cm. The ionization cross section of residual gases for energies of ~100 eV and higher is decreased approximately inversely proportional to the energy of electrons [3, 4], Fig. 1. One can assume that in ionization of the residual gas contribute generally the Larmor electrons moving along the parts of orbits closer to cathode. It can be assumed that over several cyclotron periods the path length of the ionizing electron is of the order of the length of the Larmor orbit. The ionization results in an appearance of positive ions accelerated towards the cathode. Their energy is determined by the average static electric field. In the industrial CWM-100L magnetron the ions energy is varied from 0 to ≈20 keV. The ions accelerated by the cathode voltage hits cathode.

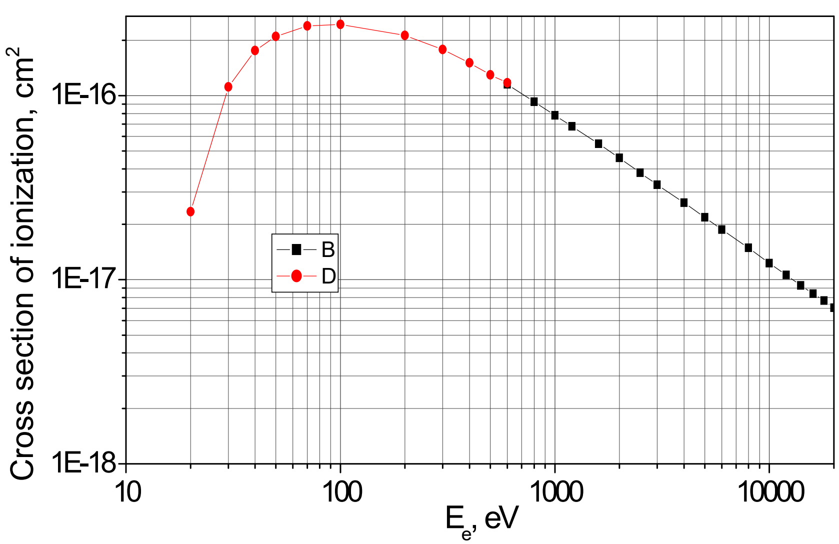

Fig. 1. Cross section of ionization of nitrogen vs. the electrons energy. Trace B was taken from Ref [3], trace D was taken from Ref. [4].

We considered ionization by 1 keV electrons. The ionization cross-section is ~ $8 \cdot 10^{-17}$ cm^2. For the CWM-100L magnetron, the probability to create an ion on the length of Larmor orbit at the vacuum pressure ~$5 \cdot 10^{-6}$ torr is ~$3 \cdot 10^{-5}$.

Thus, for the emitted current of ≈6 A the ion flux is ≈$2.7 \cdot 10^{15}$ ions/s at the energy ≤20 kV.

For the yield of the sputtered tungsten neutral atoms the SRIM program [5] was used. In the simulations was assumed normal incidence of the nitrogen ions into the tungsten target at room temperature.

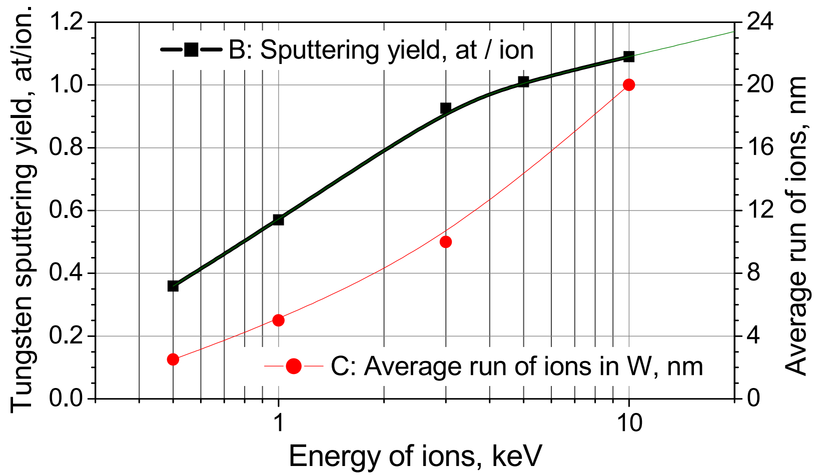

Fig. 2. Dependence of the sputtering yield on the energy of ion (black dots) and the average ion penetration depth into the cathode (red dots). Olive line is an extrapolation.

As a result one can expect a loss of tungsten from the cathode ~ 3 g/1000 h, which covers the magnetron interior with average thickness of ~ 40 μm [6].

The yield of sputtered cathode neutrals greatly depends on the atomic mass numbers of the residual gas, Fig. 3.

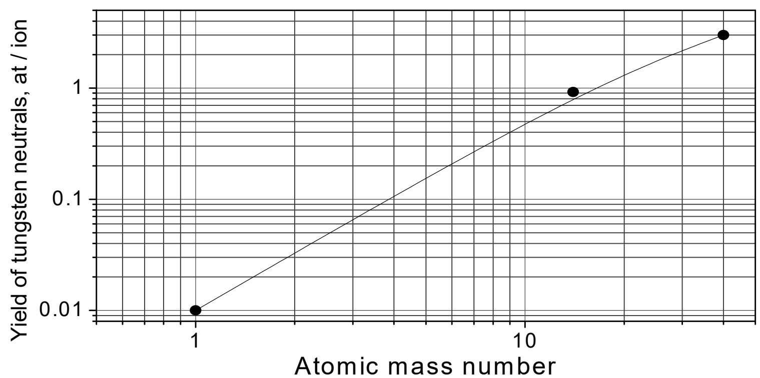

Fig. 3. The yield of the neutrals sputtered from tungsten cathode in dependence on the ions atomic mass numbers A at the ions energy of 3 keV.

The used model shows that an improvement of the magnetron vacuum e.g., by the built-in ion pump, may significantly reduce the residual gas pressure reducing the sputtering.

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