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LIFETIME OF TITANIUM FILAMENT AT CONSTANT CURRENT

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Introduction

Titanium Sublimation Pump (TSP) represents the most efficient and the least expensive method to produce Ultra High Vacuum (UHV) in storage rings. In ISABELLE, a proton storage accelerator under construction at Brookhaven National Laboratory, for example, TSP provides a pumping speed for hydrogen of $> 2 \times 10^6$ ℓ/s. Due to the finite life of titanium filaments, new filaments have to be switched in before the end of filament burn out, to ensure smooth operation of the accelerator.

We have therefore studied several operational modes[1] that can be used to activate the TSP. The constant current mode is a convenient way of maintaining constant evaporating rate by increasing the power input while the filament diameter decreases as titanium evaporates. The filaments used in this experiment were standard Varian 916-0024 filaments made of Ti 85%, Mo 15% alloy. During their lifetime at a constant current of 48 amperes, the evaporation rate rose to a maximum at about 10% of their life and then flattened out to a constant value, 0.25 g/hr. The maximum evaporation rate occurs coincidently with the recrystallization of 74% Ti 26% Mo[2] from microstructure crystalline at higher titanium concentration to macrostructure crystalline at lower titanium concentration. As the macrocrystal grows, the slip plane develops at the grain boundary resulting in high resistance at the slip plane which will eventually cause the filament burn out due to local heating.

Experiment

The composition of Varian Ti filaments is 85% titanium and 15% molybdenum. They are 6 inches long and 0.08" in diameter as received from the vendor. They were mounted on the titanium sublimation cartridge which in turn was inserted in the center port of a modified standard ISABELLE pumping station shown in Fig. 1.

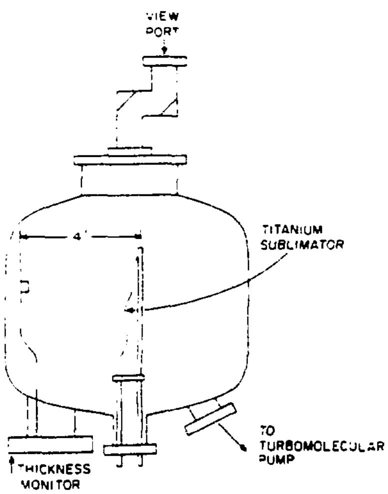

Fig. 1. Experimental set-up.

Veeco's QM-300 Kronos Thickness Monitor (Kronos) was used to measure the deposition rate of titanium. The thickness reading from Kronos was calibrated against the film thickness measurement by interferometer on a glass slide which was placed at the same radius as the quartz crystal of Kronos. E. Ritter of the Chemistry Department carried out the calibration for this experiment. The view port consisted of two parrallel stainless steel plates 45° to the normal of incident light beam of the titanium filament. Balzer TSU 110 Turbomolecular pump was used for initial pump down. Titanium was flashed at 48 amperes after the vessel pressure reached 10^{-5} Torr or less.

Filaments were subjected to various tests under different conditions. In one test the filaments were flashed for 7 minutes in high vacuum then removed from cartridge to be weighted and the diameter to be measured. The process was then repeated until the filaments burned out while flashing. In the second test the filaments were flashed for 7 minutes and cooled down five times, before they were removed from the pumping station for measurements.

Results and Discussion

It has been shown[1] that MoTi alloy will change structure from microcrystalline at low Mo concentration to macrocrystalline structure at higher Mo concentration. This phase change happens at 26% Mo concentration by weight. This recrystallization is clearly observed in our experiment and it occurs coincidently with the maximum evaporating rate as shown in Fig. 2. The physical properties which

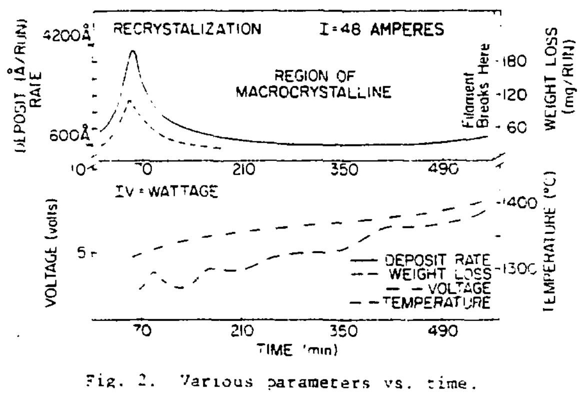

Fig. 2. Various parameters vs. time.

determine the evaporation rate of this alloy change at phase transition. For this reason, any attempt to control constant evaporation rate during the whole life time of filament must take this transformation into account. We are convinced that the constant current operation mode is the best way to operate the TSP in ISABELLE for its simplicity and reproducibility. In Fig. 2 one sees that the weight loss is linearly proportional to the evaporation rate as it should be. The resistivity of the new filament is about 140 micro-ohm cm corresponding to 4 volts in our experiment. After its recrystallization the resistivity of macrocrystalline structure is increased by about 10%, which in turn forces the temperature to rise. As the temperature increases, the resistance

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also increases. This is what we observe in our experiment which is shown in Fig. 2. The steady increase in evaporation rate per unit area due to the rise in temperature (the increment in input wattage) is compensated for by the decrease in radius, due to the evaporation of titanium. This results in a constant deposition rate in macrocrystalline region as is clearly shown in Fig. 2. The temperature fluctuation can be due to our inability to make a precision measurement in our imperfect optical system (view port) described in the previous section. Increased emissivity of the filament as evaporation progresses, increases the power loss due to radiation. This can be explained by the increasing surface area as titanium leaves the filament. The increasing surface roughness can be seen in Figs. 3 and 4.

Fig. 3. Filaments at the end of its life.

Fig. 4. Slip plane between grain boundary.

Lawson[2] was the first one to trace the increment of the emissivity to the increment of surface area. On the right in Fig. 3 we show the different appearance of filament at the end of its lifetime after normal usage. The filament abused by passing high current through it accidentally which causes the filament to melt is shown on the left in Fig. 3. It has been clear now that in the normal usage the filament lifetime is solely determined by its crystal growing behavior. At the end closest to the break-point one observes the slip plane[3] betweem two grains of macrocrystal. As the slip plane moves, the cross section area decreases, thus, increasing the local resistance right at the slip plane. This mechanism will eventually cause the filament to burn out. We believe this to be the major mechanism of filament failure in normal operation. A close-up view of the left filament in Fig. 3 is magnified in Fig. 4 to show the detail.

Acknowledment

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