

ON THE COATING OF THE SLAC KLYSTRON WINDOWS*

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1 INTRODUCTION

Since the early sixties klystron windows have been coated with a very thin film of titanium in a more or less oxidizing atmosphere (1). Somewhat later titanium nitride coated windows were advocated (2). Since then, at SLAC, the titanium was reactively sputtered or evaporated in various mixtures of oxygen, nitrogen and argon. The windows are made of 99.5% high-purity alumina, small grain, fine to medium ground on either side.

The purpose of the coating has been two-fold: suppression of the multipactor and prevention of charge accumulation. Multipactor produces heat and charge accumulation produces electric stress and both could lead to window failure.

2 MULTIPACTOR

Multipactor is an effect related to secondary emission. Titanium and titanium oxide are reported to have much lower secondary emission than alumina. However the statement applies to bulk properties. In very thin films of about 40 Angstrom, the observed secondary emission has the spectrum and the intensity of the substrate (3). This is also born out by the fact that the dynodes of photo multipliers may be coated with a thin, well conducting, layer of aluminum in order to sustain high counting rates.

Titanium nitride coatings should not fare much better. The chemical stability is certainly good but no evidence has been advanced of realistic low secondary emission in Ref. 2. Furthermore, the electrical conduction is very high, 130 $\mu\text{ohm-cm}$, affecting the control of the coating.

Hence it is questionable that the Lab ever obtained the feature of low secondary emission of window coatings, using titanium, its oxides, its nitrides or a combination thereof. Research on pure carbon coatings should lead to the same negative conclusion.

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Still, successful window coatings have been produced, i.e. some windows ran cool at nominal RF field, produced little light and had reasonable life time. The three phenomena are not necessarily correlated. However the yield has been low, 25% or so.

3 JOULE HEATING

The prevention of charge accumulation is perhaps more important than the suppression of secondary emission, in particular in view of the electric wind hypothesis, which claims that in a traveling wave electrons multipactor on the wave guide walls and propagate in the direction of the power flow, i.e. towards the window (4). We require thus that the window is slightly conducting. We remark in passing that a conducting coating discourages multipactor on an insulator since the restoring image force will be missing. The main point is that adequate surface conduction may conflict with the Joule heating produced in the RF field. In the following we try to quantify the requirements.

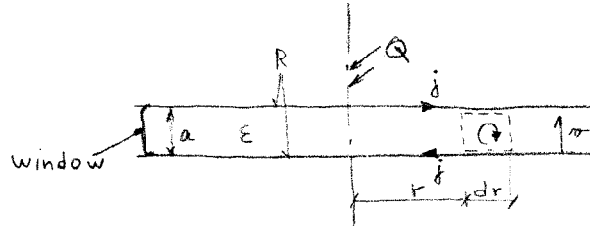
$$P_{\text{joule}} = (Z_L/R) \cdot P_{\text{ave}}$$

in which $Z_L = 500$ ohm is the wave guide impedance; R is the resistance of the surface coating in ohms/square and $P_{\text{ave}} = 50$ kW is the average RF power in the wave guide. If $R = 10$ Megohm/sq, $P_{\text{joule}} = 2.5$ Watt, i.e. 5 W for both sides of the window, i.e. about the maximum one would accept. Thus the lower limit of the surface resistance is 10 Megohm/sq.

4 CHARGE ACCUMULATION.

The accumulated charges equalize in a rather complicated fashion. We assume there is a charge blob $-Q$ somewhere on one side of the window. The electrostatic forces move conduction electrons on either side towards the rim of the window. We call this the fast transient. After this transient the window is neutral as such, i.e. $-\frac{1}{2}Q$ remains on the side which had the charge blob, somewhat redistributed of course, and $+\frac{1}{2}Q$ is induced on the other side of the window. The relaxation of the double charge layer is called the slow transient. It depends on the pulse duration, ≈ 5 usec, and the time between pulses, ≈ 5 msec whether one or the other charge relaxation time lead to charge build-up and electric stress.

We start with the slow relaxation time, because the geometry of the problem is easier. We choose the center of the charge blob in the origin of the (infinite) plate. Hence the potential difference v and the surface current j are functions of r and t . Note that j is in A/m.



Problems of this kind lead to the "telegrapher's" equation, which may be simplified further by neglecting inductance vs surface resistance and conduction across the slab vs the displacement current. This leads to:

$$\partial v / \partial r + 2Rj = 0$$

$$\partial j / \partial r + (\epsilon/a) \partial v / \partial t = 0$$

Separation leads to:

$$\partial^2 v / \partial r^2 - k^2 \partial v / \partial t = 0$$

$$\partial^2 j / \partial r^2 - k^2 \partial j / \partial t = 0$$

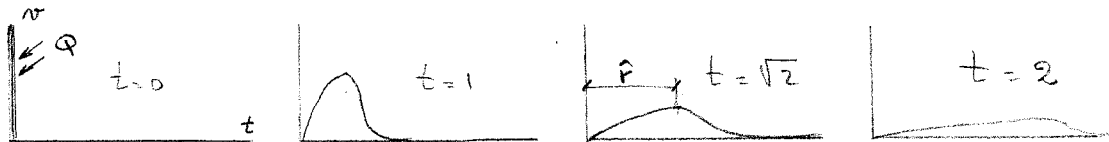
in which $k^2 = 2\epsilon R/a$. A general solution is similar to the diffusion of heat:

$$v(r,t) = krt^{-3/2} \exp(-\frac{1}{4}k^2 r^2/t)$$

By integration of the surface charge $\omega = \epsilon v/a$ we find how to normalize for the total charge:

$$Q = 2\pi^{3/2}/R$$

The general solution would be a physical reality if we assume that the charge blob at $t = 0$ is a point source in the origin. The blob would spread out in the following fashion:



The peaks move with velocity $d\hat{r}/dt = 1/(k^2\hat{r}) = 1/(k\sqrt{2t})$. The time it takes for the peak to reach the periphery $\hat{r} = 4$ cm is given by:

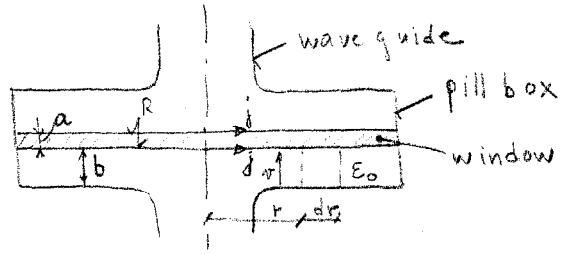
$$\tau_{\text{slow}} = \frac{1}{2}k^2\hat{r}^2 = (\epsilon/a)R\hat{r}^2 \approx 400 \mu\text{sec.}$$

This time constant may be considered to be the slow relaxation time constant.

The fast transient equations are of the same type, but the coefficients are different and not altogether constant. Where I have been hand-waving shows the following figure:

$$\partial v / \partial r + Rj = 0$$

$$\partial j / \partial r + (\epsilon_0 / b) \partial v / \partial t = 0$$



Clearly the parameter b is not constant because of the wave guide entering the pill box, but we may define a new propagation constant:

$$k_{\text{fast}}^2 \approx \epsilon_0 R / b,$$

so that $k_{\text{slow}}^2 / k_{\text{fast}}^2 = 2\epsilon_r b / a \approx 100$

Hence $\tau_{\text{fast}} = 4 \text{ usec}$

Whereas the slow relaxation time constant is small enough to ensure that at each new RF pulse all previous charges have leaked away, the fast relaxation time constant is comparable to the pulse duration, so that a source which sprays a trickle charge on the window will build up electric stress during the RF pulse. Since τ is proportional to R , reduction of the latter by an order of magnitude would probably cure the effect, but this would entail an equally larger Joule heating. So, here lies the conflict.

5 THIN FILMS

High resistivity thin films consist of a continuous insulator matrix in which metal particles are dispersed, the so-called cermet (5). The resistivity depends in first instance on the ratio metal-insulator, usually a metal oxide. The resistivity range of cermets is extraordinary, say, from $10E-5$ to $10E10$ ohmcm, i.e. from the resistivity of pure metal to the resistivity of pure insulator. Hence it is understandable that a few percent error in the ratio leads to large fluctuations in the resistivity, typically one or two orders of magnitude.

It seems therefore impossible to achieve the right value without monitoring the resistivity of the cermet. Unfortunately, monitoring alone is not sufficient; we have also to deal with aging, stabilization and the high temperature bake of the klystron. Also erosion may play a role.

Upon the first exposure to ambient air, the film, consisting on the average of a dozen or so atomic layers, is bound to be modified chemically or physically, because the bulk properties of the substance do not count here. The subsequent bake, when mounted on the klystron, at 550°C for 72 hours or longer, is presumably modifying the resistivity again. No quantitative comments are available concerning the erosion by the electric wind. Tests are underway to determine the thermo-luminescence of XK5 windows with many service hours.

Hence the foremost requirement for a coating installation would be a resistance monitor, aging and baking facilities and possibly trimming.

6 ANISOTROPIC FILMS.

We return now to the possible conflict of Joule heating vs adequate charge removal. A way out would be to coat the window so that conductivity in the direction of the projected electric field is small, but is large in the direction perpendicular to the electric field. As a first approximation and test, one would prepare a film which conducts well along straight parallel lines, which are parallel to the broad side of the wave guide and conducts less well perpendicular thereon. In numbers: $10 E7$ ohm/sq in the direction of the electric field and $10 E5$ to $10 E6$ ohm/sq in the other direction. A wire mask and a point or line source of the appropriate geometry could realize this.

7 CONCLUSION

Secondary emission is not likely to be suppressed in thin films. Accumulated charges leak away with two time constants. The fast time constant should be short compared to the pulse duration, and the slow time constant should be short compared to the time between pulses. The Joule heating may be prohibitive in reaching adequate charge removal. The joule heating may be reduced by films which conduct little in the direction of the electric field and much better in the perpendicular direction.

8 REFERENCES

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