Letters to the Editor

Growth of Anodic Ta_2O_5 Films during Illumination with Ultraviolet Light

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IT has been reported by Bär[1] and by Young[2] that the optical thickness of an anodic Ta_2O_5 film formed at a given voltage may be increased by a factor of two or three if the film is illuminated during formation with light of wavelength less than 3000 A. The thickness calculated from capacitance measurements was also found to be increased but by a smaller amount. It is the purpose of this note to describe recent experiments which indicate that the thick films formed under such conditions are porous in structure.

A tantalum specimen was anodized at 20 volts in 2 percent H_2SO_4 at 50°C while being irradiated on one side with light from a mercury vapor lamp. The photocurrent on the illuminated side was about 0.008 ma/cm². The formation was interrupted periodically, and the thicknesses of the oxide film on the irradiated and dark sides of the specimen were measured by comparison with an optical thickness step gauge. It may be seen from Fig. 1 that the thickness of the oxide film on the dark side increased rapidly to about 400 A and then remained nearly constant. The thickness of the film on the illuminated side was nearly equal to that on the dark side until about 3000 seconds, after which it grew more rapidly. After about 8000 seconds the growth rate of the film on the illuminated side was constant at 0.038 A per second. The thickness of film on the illuminated side calculated from the measured capacitance assuming the same dielectric constant as for the dark side was 940 A while the optical thickness was 2575 A. When this specimen was etched in HF the film on the illuminated side dissolved very much more rapidly initially than that on the dark side, as shown in Fig. 2, but the rate of solution of the illuminated film decreased as it dissolved.

After the formation a nitrocellulose replica was made of the oxide film surface and examined in the electron microscope. It was found that the film contained about 10^7 to 10^8 pits per square centimeter of surface, each pit having a diameter of about 100 A. Films formed without ultraviolet illumination showed almost no surface structure.

It is believed that these results indicate that the oxide film formed during illumination with ultraviolet light consists of a thick porous outer layer over a thin dense inner layer. A similar oxide structure is known to form on aluminum anodized in 15 percent sulfuric acid.[3] The optical thickness of such a film is greater than the thickness calculated from capacitance measurements because the measured capacitance is very approximately that of the thin inner film in series with the resistance of the porous outer film. The irradiated film corrodes initially at a much greater rate because the corroding solution penetrates the pores of the outer film which then dissolves very rapidly. When the porous film has been removed the inner film dissolves at approximately the same rate as does the film on the dark side.

The mechanism by which the ultraviolet light results in the formation of the porous film is not understood. Because of the similarity of the structure produced by this process with that produced by anodic oxidation of aluminum in 15 percent H_2SO_4, it seems likely that the mechanisms may be similar. A further investigation of this effect is in progress.

[1] W. Bär, Z. Physik 115, 658 (1940).
[2] L. Young, Trans. Faraday Soc. 50, 153 (1954).
[3] Keller, Hunter, and Robinson, J. Electrochem. Soc. 100, 411 (1953).

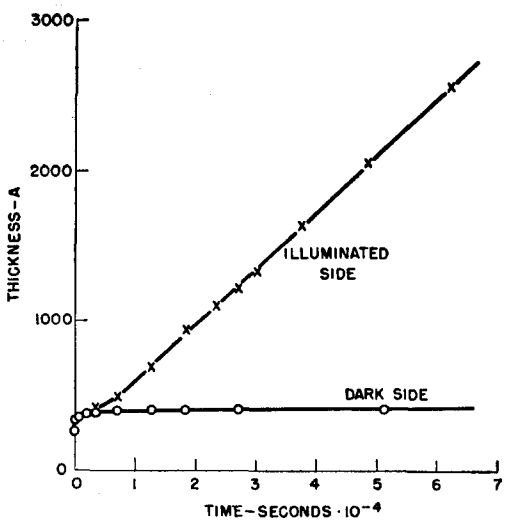

FIG. 1. Thickness of anodic oxide films as a function of time of formation.

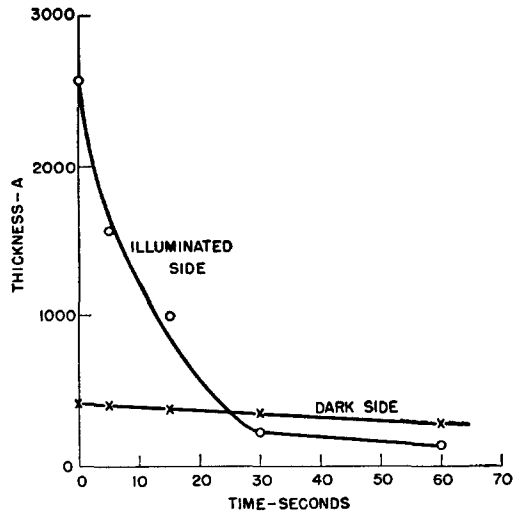

FIG. 2. Thickness of anodic oxide films as a function of time of etching in HF.

Laminar Flow in Channels with Porous Walls at High Suction Reynolds Numbers

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THE problem of laminar flow in channels with porous walls has been considered recently by Berman[1] for the case of low Reynolds numbers. It is the purpose of this paper to extend the problem to very high Reynolds numbers by a method which becomes asymptotically exact as the Reynolds number increases indefinitely.

The problem which Berman treated was that of a laminar incompressible steady flow entering a two-dimensional channel and through whose walls there is a uniform suction velocity.

Berman has shown that the flow may be defined by a stream function of the form

$$\psi = \bar{u}d f(\lambda)[1 - x/L], \qquad (1)$$

where λ is y/d and L is the length from the entrance to the point where all the fluid has entered the walls.

The function f satisfies differential equation

$$f'''=R_s(ff''-f'^2+k_1) \tag{2}$$

with

$$f(0)=f''(0)=f'(1)=0,$$
$$f(1)=0.$$

Here primes denote differentiations with respect to λ, k_1 is a constant to be determined from the boundary conditions, and R_s is the suction Reynolds number.

Thus, it is clear that a complete solution of the problem only involves solving (2) and determining k_1 from the associated boundary conditions. By expanding f in a power series in R_s, Berman obtained a solution valid for R_s of the order of unity. We now consider the case of very high R_s: As a first step we will consider the limiting case of R_s infinite.

In this case (2) becomes

$$ff''-f'^2+k_1=0 \tag{3}$$

with

$$f(0)=f''(0)=0, \quad f(1)=1.$$

The formal procedure of letting $R_s\to\infty$ in (2) does indeed give the perfect fluid solution as may be verified by writing the corresponding perfect fluid problem. The boundary condition which must be dropped since the equation is now of lower order, corresponds to the "no slip" condition on the walls.

The proper solution of (3) is

$$f=\lambda, \quad k_1=1. \tag{4}$$

From this we see that the x-velocity at any point is independent of y. In the case where the Reynolds number is very high, one might expect that this same situation would exist over most of the channel except very near the walls, where there would be a thin boundary layer of slowed up fluid. In this case $f=\lambda$ would be a good approximation to the *magnitude* of the function even near the wall where the actual function's derivative must abruptly approach zero. These considerations form the basis of the following approximation scheme:

First, we integrate (2) to obtain

$$f''=R_s\Big(ff'-2\int_0^\lambda f'^2d\lambda+k_1\lambda\Big). \tag{5}$$

Here we have put in the boundary condition $f''(0)=0$. In this equation we now replace the term ff' with $\lambda f'$ and $\int_0^\lambda f'^2d\lambda$ with λ, in accordance with the statement that $f=\lambda$ is a good approximation to the magnitude over all the range. Notice that the integral is not very sensitive to the fact that the integrand really departs from unity in the close vicinity of the wall. Now the differential equation (5) becomes

$$f''=R_s[\lambda f'+(k_1-2)\lambda]$$
$$f(0)=f'(1)=0; \quad f(1)=1, \tag{6}$$

and the solution which satisfies the boundary condition is:

$$f=\frac{\lambda-I(\lambda)}{1-I(\lambda)} \tag{7}$$

with

$$k_1=\frac{1-2I(1)}{1-I(1)} \tag{8}$$

where

$$I(\lambda)=\int_0^\lambda \exp\Big[\frac{R_s}{2}(\lambda^2-1)\Big]d\lambda.$$

For large values of R_s, it may be shown that

$$I(\lambda)\leq I(1)\simeq R_s^{-1}+R_s^{-2}+\cdots. \tag{9}$$

By examining the approximations made in the differential equation it is seen that terms of the order of $(R_s)^{-1}$ have been neglected in comparison with terms of the order of unity. Thus, it is clear that (7) and (8) are good approximations provided that R_s is sufficiently high. One might hope, in fact, that $R_s=50$ is high enough. The above may be thought of as the first step in an iteration process and the steps may now be repeated using the more accurate values. The next step is, of course, quite complicated.

The x-component of velocity is then given by

$$u=\hat{u}\Big\{1-\exp\Big[\frac{R_s}{2}(\lambda^2-1)\Big]\Big\}\Big\{\frac{1-x/L}{1-I(1)}\Big\}. \tag{10}$$

From this we can define an effective boundary layer thickness, δ, which we will define as the distance from the wall to where the velocity reaches 99 percent of the center velocity.

$$\frac{\delta}{d}=1-\lambda_{b.l.}\cong\frac{4.6}{R_s}. \tag{11}$$

So, for $R_s=100$ the "boundary layer" only occupies 4.6 percent of the channel.

The pressure along the axis ($y=0$) is given by

$$p(x)-p(0)=p\hat{u}^2k_1\Big(\frac{x}{L}-\frac{1}{2}\frac{x^2}{L^2}\Big). \tag{12}$$

Since $k_1\to 1$ as $R_s\to\infty$, it is clear that the pressure gradient is positive as compared to the case of very low Reynolds numbers; in fact, at $x=L$, where $u=v=0$, the pressure approaches the stagnation pressure of the entering (essentially uniform) flow.

[1] Abraham S. Berman, J. Appl. Phys. 124, 1232 (1953).

Variation of Noise with Ambient in Germanium Filaments*

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THE purpose of this note is to present results of some experiments aimed at a better understanding of $1/f$ noise in semiconductors.[1,2] There is evidence that the noise level is influenced by surface properties, so it was to be expected that changing the medium in contact with the surface might be accompanied by changes in noise.

Table I.

Filament resistivity and type	Current (ma)	Noise factor (db)	$\Delta F/F$
>35Ω−cm p	0.86	21.7	+0.8
35Ω−cm p	0.24	27.4	+0.8
11Ω−cm p	1.53	18.7	−0.5
11Ω−cm n	1.46	11.7	+5.5
11Ω−cm n (filament re-etched)	1.46	12.6	+3.6

F = noise factor $=\dfrac{\text{noise power for a current of 1 ma measured at 40 cps in dry } N_2}{\text{thermal noise power}}$

$$\Delta F/F=\frac{F(\text{wet } N_2)-F(\text{dry } N_2)}{F(\text{dry } N_2)}$$

The cross section of each filament was approximately 0.05 cm × 0.05 cm.

Table I shows the results of noise power measurements on two terminal filaments when the gas surrounding various filaments was changed from dry nitrogen to wet nitrogen (relative humidity 44 percent). The time between changes, which were repeated cyclically, was about 15 minutes. The values given refer to steady state readings that were reproducible over several cycles, since the first few cycles after etching generally were not reproducible.