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STEAM CONDENSATION ON ELECTROPLATED GOLD: EFFECT OF PLATING THICKNESS

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NOMENCLATURE

Q/A, heat-transfer rate [W/m²];
ΔT_S, steam to gold-surface temperature difference [K].

INTRODUCTION

EARLIER works [1–11] show that a thin coating of gold can serve as an excellent promoter of dropwise condensation. Gold is attractive because it is permanently bonded to the base metal, it does not corrode, and it offers little additional resistance to heat transfer. Certain organic promoters are effective also, even when as thin as one molecular layer [12]. The present work was designed to discover the least thickness required for a gold plate to promote dropwise condensation of steam at atmospheric pressure.

EXPERIMENTAL

The heat-transfer equipment was similar to that used earlier [8]. Condensation occurred on a vertical surface which was the circular end of a 2.54 cm dia solid copper cylinder 5 cm long. The opposite end was cooled with water or air flow. The test piece had been force-fit into a hollow Teflon sleeve with a 1.27 cm wall. Three thermocouples along the geometric axis were used to determine the heat flux (from the gradient) and the surface temperature (by extrapolation). Two independent verifications of the heat duty were obtained by metering the flow of condensate and by checking the heat pick-up from the back face of the test piece by the cooling water.

The test piece was prepared by the same procedure for each run. Any gold from the previous run was removed with 600-grade silicon carbide polishing paper, followed by alumina polishing ending with Gamal B alumina suspended in water on Gamal polishing cloth. According to the manufacturer, Gamal B has a particular size less than 0.1 micron which is well below the wavelength of light. The result was a mirror finish on the copper.

The test piece was rinsed with deionized water and placed in a well-stirred plating cell constructed all of Teflon except for the stainless steel anode. A commercial electroplating solution was used, Techni-Gold 25. This is a sulfite solution, with a trace amount of arsenic brightener, and contains no organic material.

The plating current density was held at 32 amp/m², while the plating time was controlled to fix the plating thickness. A solid-state digital timer was constructed and calibrated [13]. This turned on the plating circuit for selected times from 6 ms to 30 min. The effective thickness of the gold deposit was calculated from the measured coulombs by assuming that the plating was uniform, non-porous, with a density of pure gold. The plating efficiency was assumed to be 100% (i.e. no side reactions), and the gold ions were known to be of valence +1. The lattice spacing for the (200) crystal plane of gold is 2×10^{-10} m. In this paper a layer of 2×10^{-10} m is arbitrarily defined as one layer of gold atoms. The plating times therefore give effective plate thicknesses of from 0.1 to 30 000 layers.

After electroplating was finished, the test piece was quickly rinsed with deionized water and was placed immediately in the test chamber. The gold surface was not touched by human hands, and it was not subject to any chemical or mechanical treatment. Steam was already present in the test chamber, so condensation occurred without delay. A run time of 4–5 h was used, at which time the data were recorded and photographs were taken.

RESULTS

The results of the experimental program are summarized in Table 1. Selected curves are shown in Fig. 1, with the actual heat-transfer data included for one run only (150 layers). It is convenient to classify the results into three thickness groups. Gold deposits of 500 layers or more resulted in dropwise condensation. This was evident from the heat-transfer data and also visually as seen in Figs. 2 and 3. Deposits of 100 layers or less resulted in filmwise condensation. Pure uncoated copper also resulted in filmwise condensation. A transition region exists for deposits between 100 and 500 layers. For example with 200 layers, perfect filmwise condensation occurred once, but four cases resulted in a mixture of both filmwise and dropwise behavior on the surface. Figure 4 shows mixed condensation like this for one run with 300 layers. On four other occasions, 300 layers caused dropwise condensation only.

The classification in Table 1 and Fig. 1 is based on the heat-transfer measurements. If visual criteria only are used, the results are slightly different. Deposits of 1000 layers are needed to produce "perfect" dropwise condensation defined as every drop being a segment of a sphere as in Fig. 2. Deposits of 500 layers produced a "non-perfect" dropwise condensation with some areas repeatedly producing drops of irregular shapes as in Fig. 3.

The surprising conclusion is that a monolayer of an organic promoter and a monolayer of electroplated gold as promoter have nothing in common. This probably means

Table 1. Summary of results: effect of plating thickness on dropwise vs filmwise condensation

Equivalent layers of gold	Total runs	Number of runs with each type of condensation		
		Dropwise	Mixed	Filmwise
0	2	0	0	2
0.1	2	0	0	2
1.0	2	0	0	2
10	3	0	0	3
100	4	0	0	4
150	4	0	1	3
200	5	0	4	1
300	5	4	1	0
500	5	5	0	0
700	4	4	0	0
1000	7	7	0	0
10 000	4	4	0	0
30 000	2	2	0	0

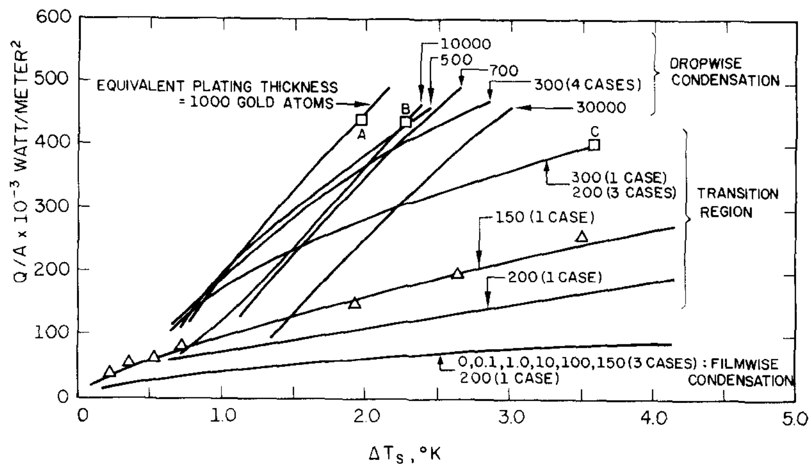

FIG. 1. Selected experimental runs showing effect of thickness of gold plate on condensation heat transfer. The equivalent thickness of a layer of atomic gold is 2×10^{-10} m.

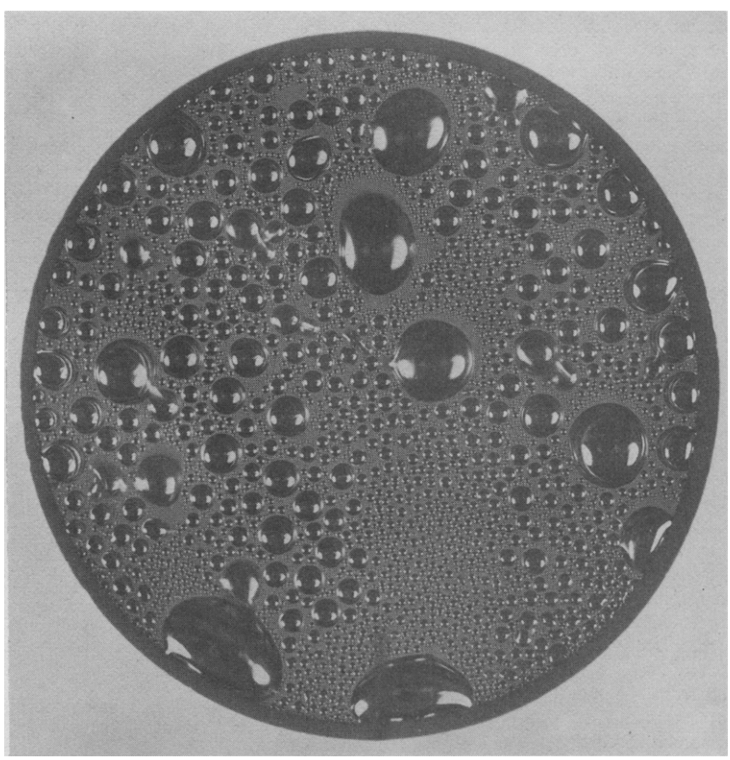

FIG. 2. Perfect dropwise condensation results with a plating thickness equivalent to 1000 layers of gold. This is Point A in Fig. 1.

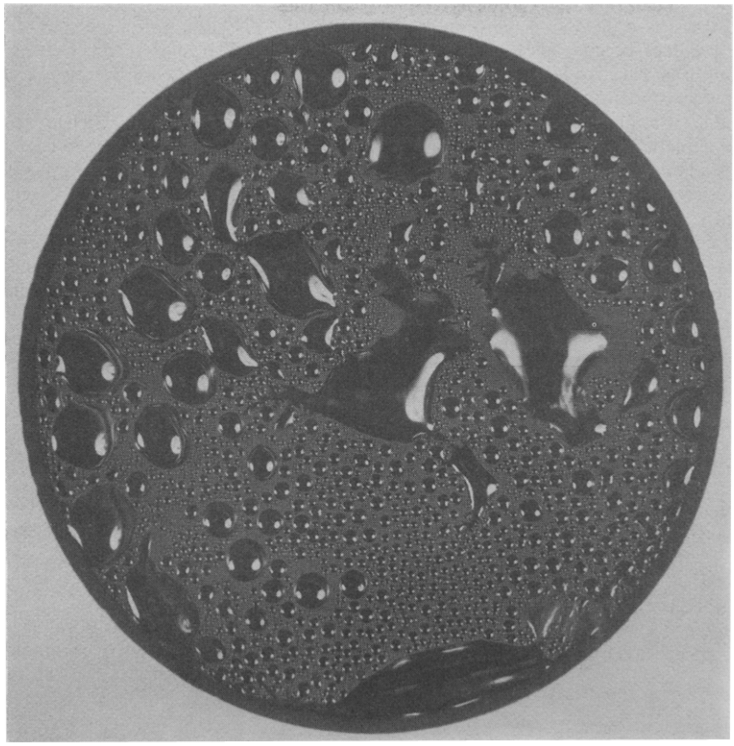

FIG. 3. Good dropwise condensation results with a plating thickness equivalent to 500 layers of gold, but with a few patches of different wettability. This is Point B in Fig. 1.

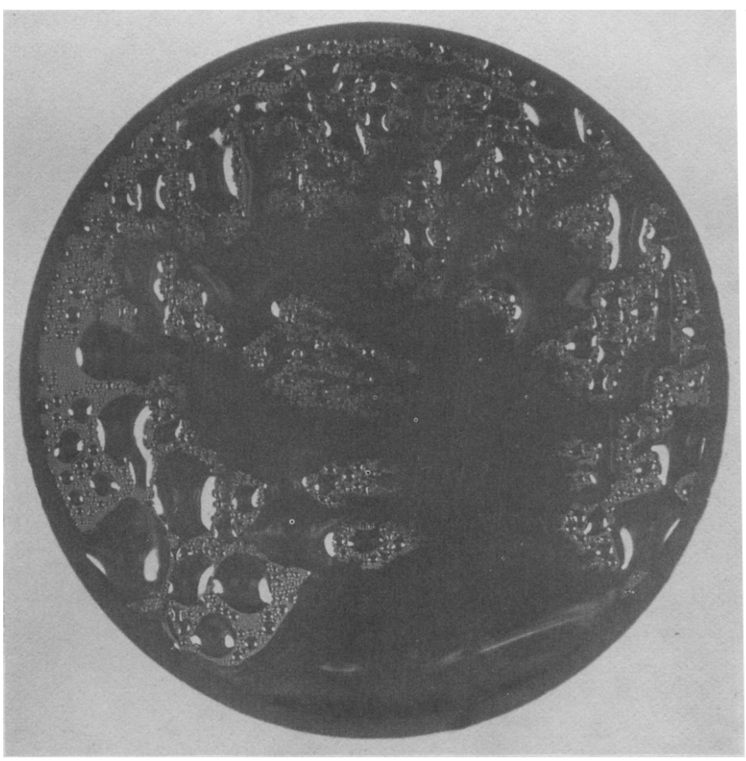

FIG. 4. Mixed filmwise and dropwise condensation results with a plating thickness equivalent to 300 layers of gold. This is Point C in Fig. 1.

that electroplated gold forms as scattered thick islands and that the substrate is not covered until the islands have all merged. At least 150 effective layers of gold must be deposited before the presence of gold affects the condensation of steam. About 1000 effective layers are needed to produce perfect dropwise condensation. This thickness is about the same as the legal minimum for gold electroplate jewelry in the U.S.A., namely 7×10^{-6} in (or 889 layers of gold). Although this is a large number, the gold thickness is less than half the wavelength of light. The monetary value of 1000 layers of gold is \$25/m^2, based on \$200 per Troy ounce. This may be an acceptable cost. It results in an increase in the condensing heat-transfer coefficient by a factor which ranged from 5 to 7 times in Fig. 1, depending on the ΔT.

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