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DEVELOPMENT OF CRYOGENIC TARGETS FOR LASER FUSION*

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INTRODUCTION

In the development of targets for laser fusion, there is considerable interest in producing a uniform spherical shell of liquid or solid deuterium-tritium mixture (1:1 ratio). It is felt that fuel in this form, compressed and heated by laser beams, would give optimum energy yield.[1-2] Fabrication of this target begins with selection of glass microballoons, 80-110 μm diam and 1-2 μm wall, for uniformity in diameter and wall. These are filled by diffusion at 400°C and high pressure and rapidly cooled to room temperature to entrap the gas. Various fills have been used: D_2, T_2, and D-T, ending with 50-190 atm at 300 K, which result in upper condensation temperatures of 29-38 K. If all the fuel is condensed uniformly on the inner surface of the container, the solid layers are calculated to be 0.5-2.1 μm thick.

A previous paper[3] described experiments on some targets cooled through four types of heat transfer: (1) radiation to a 4 K envelope; (2) conduction through a glass fiber support; (3) conduction through exchange gas; and (4) conduction to a stream of cold He from above. The first three types resulted in condensate collecting mostly in the bottom of the glass shell, illustrating the effect of gravity and surface tension. However, the stream of cold He set up a thermal gradient which balanced gravity and resulted in condensate spread uniformly or even excessively at the top. Therefore, it was concluded that this cooling method would have the greatest

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feasibility in an actual target chamber, for it probably would least interfere with the laser beam or resulting plasma.

In the present experiment, cooling of the target was done by a high-conductivity fiber attached at one end to the glass shell. This method should be superior to the cold He stream, for it would probably provide better control over the condensate, there would be no gas to spoil vacuum or interfere with the plasma, and thermal radiation shields could be omitted. However, the fiber must conduct away 14 μW of heat resulting from 300 K radiation without adding many electrons to the plasma. For this conductance, a fiber with thermal conductivity k must have a minimum diameter $d_m \cong 40/k^{1/2}$. Since the number of electrons varies as mass or ρd^2, where ρ is density, we seek materials with large values of k/ρ. Several potential materials are given in Table I. Their feasibility will depend on availability of small diameters, mechanical stability of the fiber, and the maintenance of the high conductivity attained in large samples.

EXPERIMENTAL

Fibers of 17 μm Cu and 12 μm Au, each 1 mm long, were used. Considerable care was taken in making the fiber end square and in attaching it to the target with small amounts of epoxy, but success was not always attained. The other end of the fiber was epoxied to a 0.75 mm diam Cu wire which was soldered to a cryostat tip. Here a heater and thermocouple were attached for temperature control and measurement. Although the thermocouple temperature gives a poor indication of the target temperature, it is useful in identifying temperature changes. The apparatus was the same as used previously[3], but the radiation shields around the target were eliminated. With this arrangement, it was not surprising to find that light from the illuminating lamp seemed to have no effect on the target. The target image was observed in the microscope in natural orientation and was recorded on Polaroid 107 black and white prints or on Kodak Ektachrome 7242 movie film.

RESULTS

Results with Cu fibers in two orientations are described here. Two glass microballoons, both $\sim$ 94 μm diam and 0.7 μm wall, were filled with D_2-T_2 (1:1) at the same time, resulting in 187 atm at 300 K. Liquid should appear at $\sim$ 38 K and the greatest thickness of a uniform layer of condensate should be 2.0 μm. The fiber of each target was cemented to a loop of Cu wire so that they were parallel to each other but the heat flow from each was in opposite directions.

In one orientation, the fibers were approximately vertical. Target A was below its fiber and Target B was above its fiber, and this orientation should show the effect of gravity directly. The targets are shown in Figs. 1-3 in order of increasing thermocouple temperature T_{tc}, beginning with the fuel as a frozen spheroid at $\sim$ 16 K. Figure 1 shows melting in both targets as might be expected. In Figs. 2 and 3, Target A continues with no surprises, but it was disappointing to find lack of condensate at the bottom of the shell (which indicates the radiation heating could not be overcome). In looking at these pictures, one must block out imperfections, such as, dirt or excess cement (seen on Target A shell at the left of the fiber). As a surprise, Target B condensate at 17.76 K (Fig. 2) forms a mist state before becoming a spread-out layer, approximately uniform, which persists between 18 and 25 K. At higher temperatures, the layer thins, not quite symmetrically, until only gas is present, as illustrated in the 46 K picture of Fig. 3. All the states were stable at a given temperature, were reversible, and were reproduced on different days. Of course, the fairly uniform layer of condensate in Target B in the 18-25 K range is the desirable form for a laser fusion target, and its insensitivity to T is a convenience. However, its formation is puzzling if only a simple consideration of gravity and thermal gradient is made. Perhaps, the appearance of the intermediate mist state might provide a clue. Also close observation of the solid and liquid near freezing when heated or cooled indicates the possible shifting of layers. As the system has three components (D_2, DT, and T_2) one might expect some kind of thermal separation in the condensed phases.

For an incomplete reversal of target positions, the Cu wire loop was turned so that there was also a back-front reversal and the fibers were left ∿ 30° off the vertical. Figures 4-5 show that the condensate behavior, as the targets were warmed from frozen spheroid to spread-out layer, went along with the target position (above or below the conducting fiber). This orientation caused almost reversal of condensate behavior. In particular, the diffuse state in Target A at 18.00 K, illustrated in Fig. 4, resembles the mist state in Target B at 17.76 K (Fig. 2).

The results of this experiment are much different from those obtained by Henderson et al.[4] They observed that the condensed DT film was thinnest nearest the shell-fiber contact point, regardless of the orientation. This occurred even with the contact at the shell bottom, in which case, the thermal gradient should reinforce gravity in producing a thicker film at the bottom. It is difficult to explain the differences between the results of these two experiments.

CONCLUSION

The best method of cooling D-T to get the condensate into a uniform spherical layer seems to be through a high conductance fiber. One end of this is cemented to the bottom of the microballoon container and the other end kept at 2-10 K above the freezing temperature. Future tests will be made with thin fibers of various materials in order to minimize mass.

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Table I

Some Potential Materials for Conducting Fiber

Material	k^a ($W\ cm^{-1}\ K^{-1}$)	ρ ($g\ cm^{-3}$)	k/ρ	d_m (μm)
Aℓ pure, annealed	200	2.7	74	3
Cu pure, annealed	150	9.0	17	3
Be single crystal	25	1.8	14	8
Aℓ pure, polycrystal	36	2.7	13	7
Si doped	32	2.4	13	7
Ag pure, annealed	110	10.5	10	4
Sapphire single crystal	40	4.0	10	6

[a] Thermal Conductivity of Solids at Room Temperature and Below, a Review and Compilation of the Literature, G. E. Childs, L. J. Ericks, and R. L. Powell, NBS Monograph 131, September 1973.

FIGURE CAPTIONS

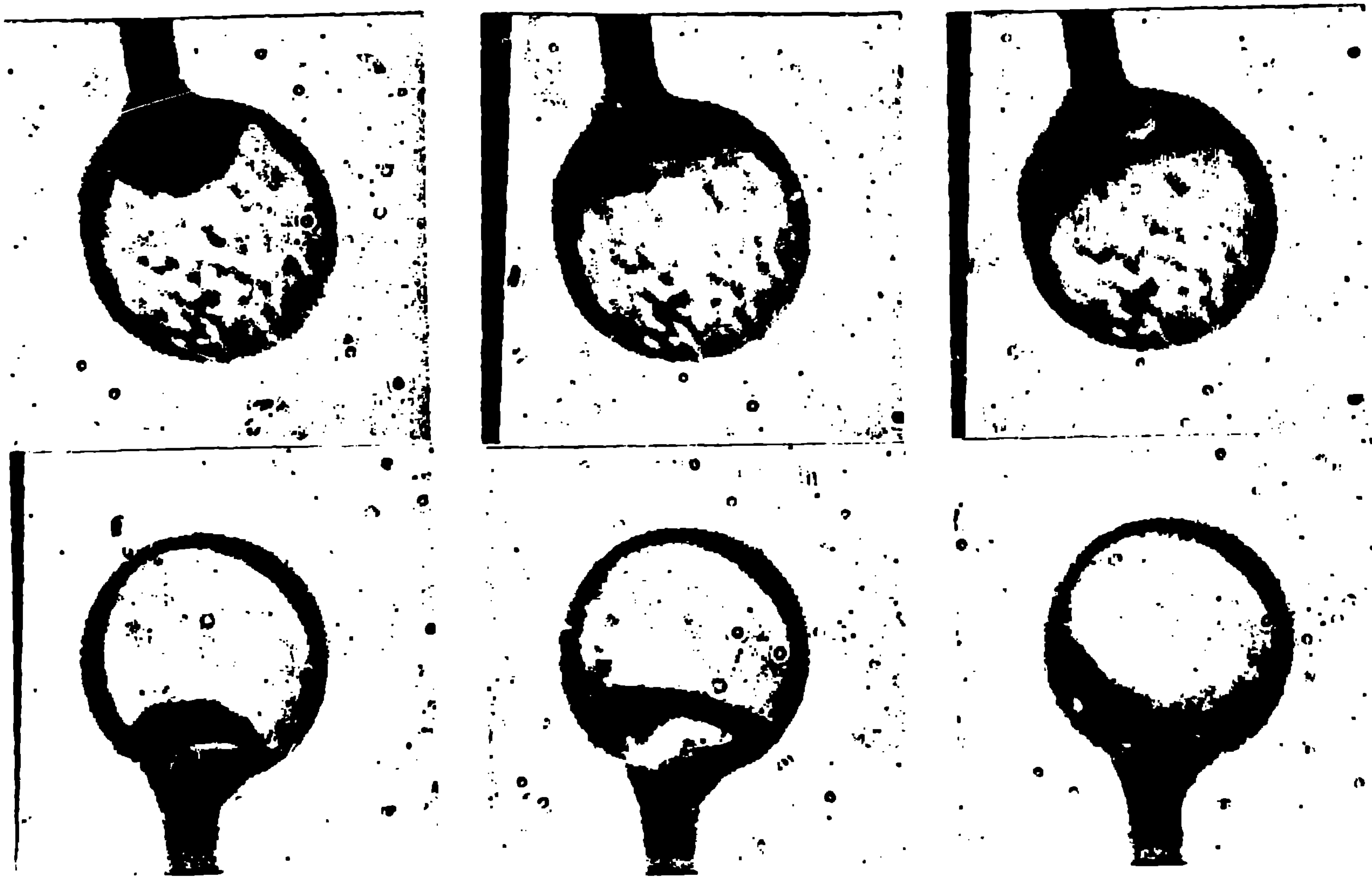
Fig. 1. Targets with vertical fibers at thermocouple temperatures 16.30-17.74 K. Target A is at top and Target B is below.

Fig. 2. Targets with vertical fibers at thermocouple temperatures 17.76-17.88 K. Target A is at top and Target B is below.

Fig. 3. Targets with vertical fibers at thermocouple temperatures 20.0-46 K. Target A is at top and Target B is below.

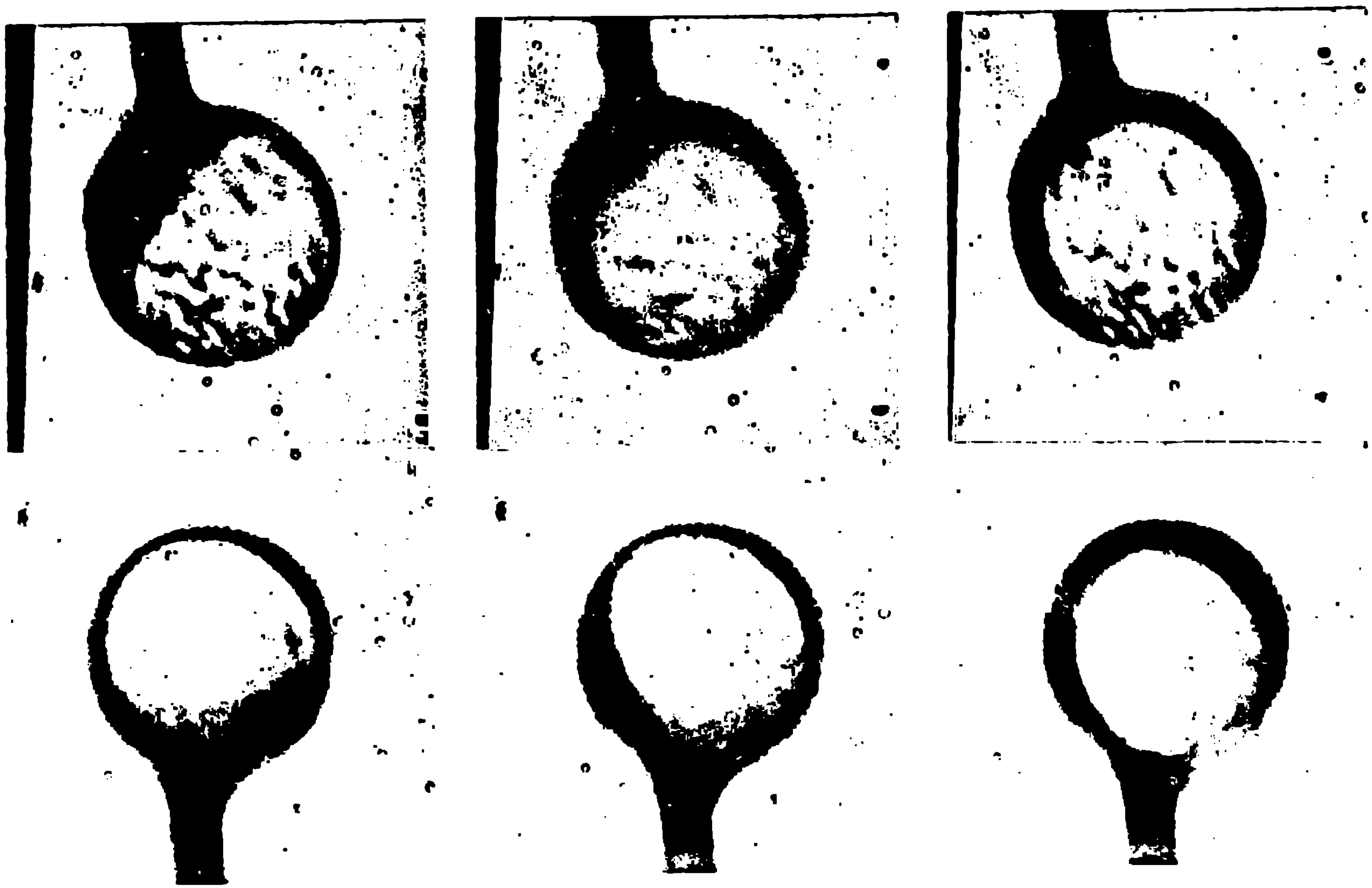
Fig. 4. Inverted targets with non-vertical fibers at thermocouple temperatures 16.20 - 18.00 K. Target B is at top and Target A is below.

Fig. 5. Inverted targets with non-vertical fibers at thermocouple temperatures 18.04 - 53 K. Target B is at top and Target A is below.



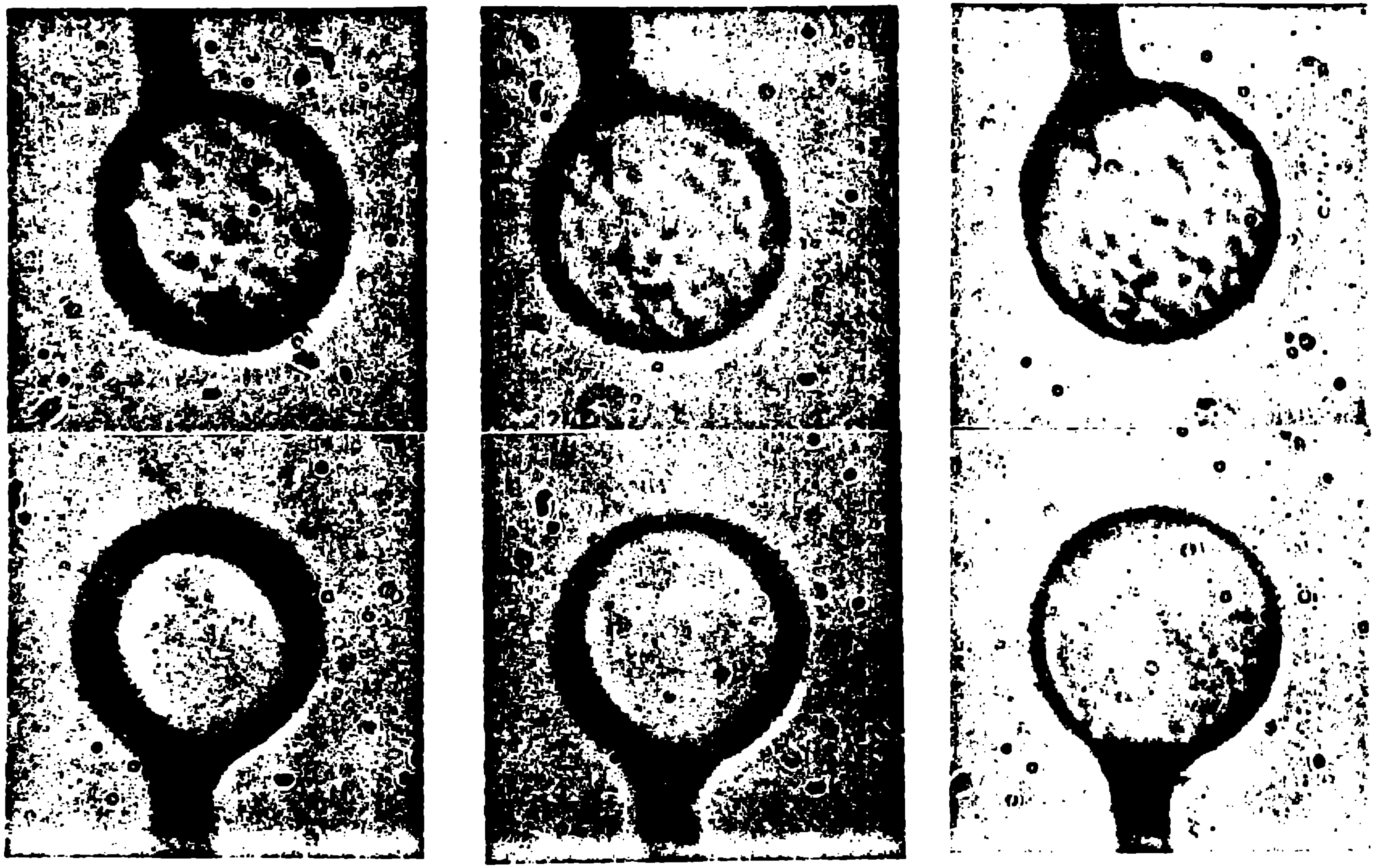
$T_{tc}(K)$ 16.30 17.70 17.74

Fig.1



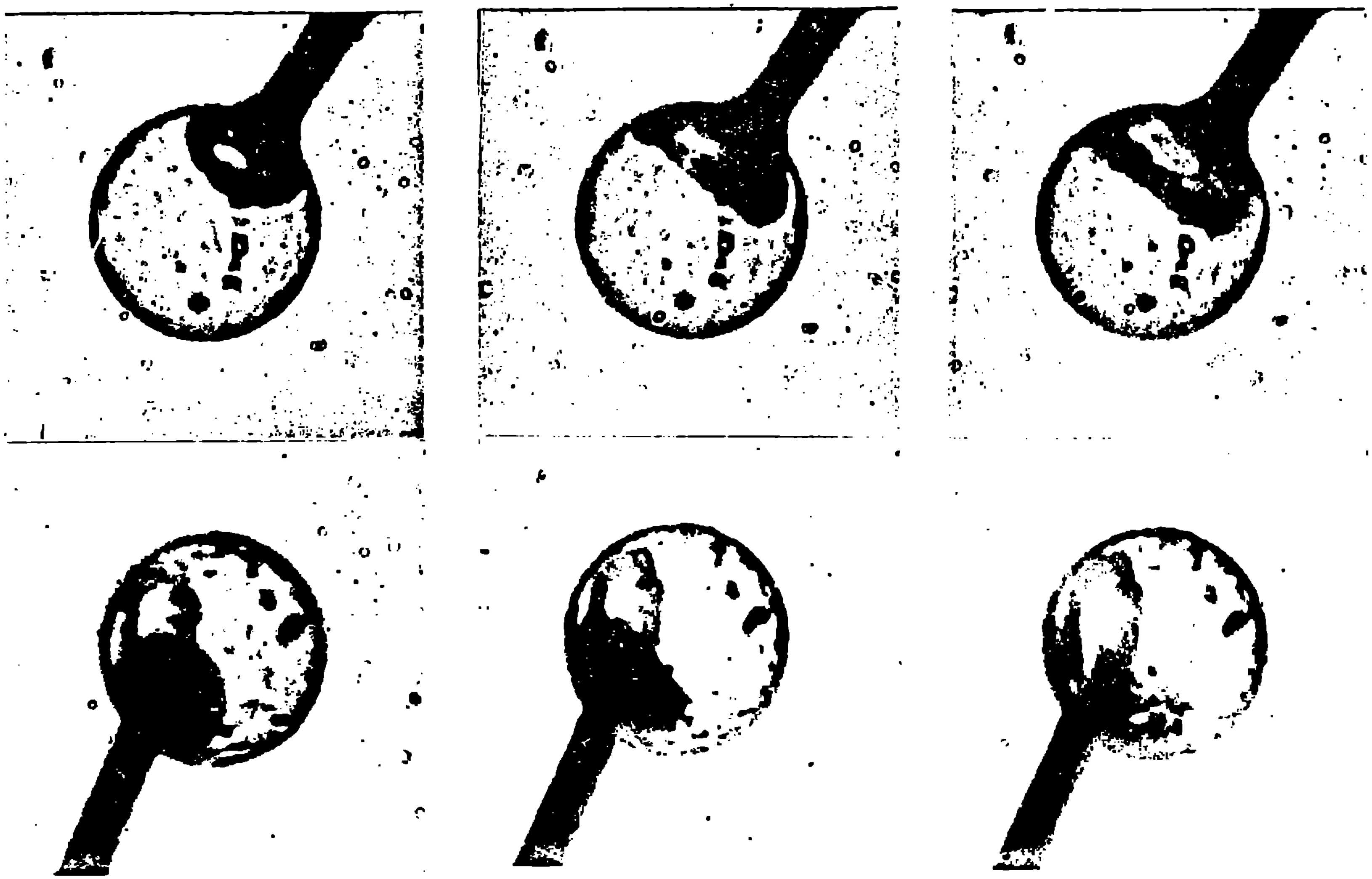
T_{tc}(K) 17.76 17.80 17.88

Fig.2



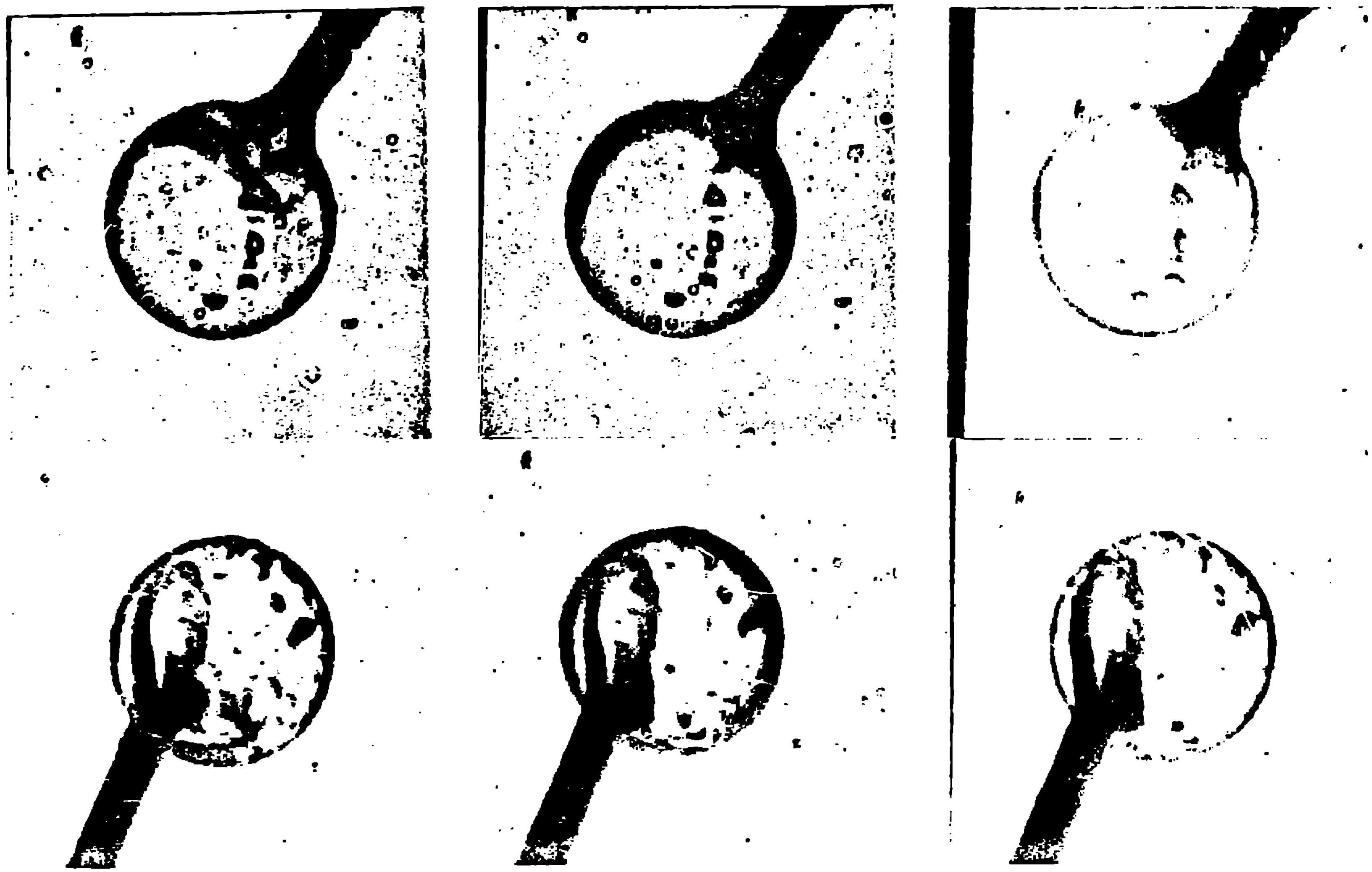
$T_{tc}(K)$ 20.0 30.0 46

Fig.3



T_{tc}(K) 16.20 17.90 18.00

Fig.4



$T_{tc}(K)$ 18.04 18.10 53

Fig.5