Int. J. Heat Mass Transfer. Vol. 34, No. 11, pp. 2833–2835, 1991
Printed in Great Britain

0017–9310/91 \$3.00+0.00

Surface materials with dropwise condensation made by ion implantation technology

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(*Received* 21 *August* 1990 *and in final form* 10 *December* 1990)

Abstract—A new method producing dropwise condensation is presented by preparing surface alloys which possess low surface energy in the metallic surface. Four kinds of surface alloys of copper are made by applying ion-implantation technology. Steady dropwise condensation of steam is formed on the four surfaces. The characteristics of the alloy surfaces are analysed.

1. INTRODUCTION

IN ORDER to obtain dropwise condensation on a metallic surface, its surface energy must be reduced. Tanasawa [1] classified methods employed to maintain dropwise condensation into five categories, and pointed out that the main problems of the methods are short lifetime, high cost, additional heat resistance, etc. Thereby, he stressed, "the industrial use will not be achieved, unless the low energy surface are devised". It is not only a heat transfer problem, but also a problem of surface science and surface technology.

To solve the problems, ion-implantation technology was used to make new surface materials achieve dropwise condensation.

2. THE METHOD OF SURFACE TREATMENT

Ion-implantation technology was employed to prepare copper surface alloys. Preliminary treatment was made by polishing to remove fouling and oxide film on the copper surfaces. The elements, He, Ar, N, and H were used respectively to produce four kinds of surface alloys of copper: Cu–He, Cu–Ar, Cu–N, and Cu–H.

It was found that both ion-implanted dose and ion-implanted energy have effects on the surface energy. According to the wettability of alloy surfaces, the optima of ion-implanted dose and energy for He, Ar, N, and H were obtained (Table 1).

The wettability of the four alloy surfaces was as follows: Cu–N < Cu–He, Cu–Ar < Cu–H.

3. EXPERIMENTAL APPARATUS FOR HEAT TRANSFER OF DROPWISE CONDENSATION

3.1. *Condensing surface*

The apparatus consists basically of a condensing copper block, which is shown in Fig. 1.

3.2. *Experimental loop*

The experimental loop is shown in Fig. 2.

3.3. *The range of experimental parameters*

The flow rate of cooling water ranged from 0.2 to 2.0 m^3 h^{-1} and the inlet temperature of it was about 25°C. Steam was condensed under atmospheric pressure.

3.4. *Determination of heat transfer coefficient*

The determination of the heat transfer coefficient of condensation was as follows:

heat flux

$$Q = \frac{\lambda \Delta t}{\delta} \quad (1)$$

surface temperature

$$T_s = \frac{Q\delta_1}{\delta} + T1 \quad (2)$$

heat transfer coefficient

$$h = Q/(T_v - T_s). \quad (3)$$

4. EXPERIMENTAL RESULTS

The steady dropwise condensation of steam was obtained on the four alloy surfaces, respectively.

Figure 3 shows the effect of flow rate of cooling water on the heat transfer coefficients.

Figure 4 shows the effect of nitrogen-implanted conditions on heat transfer coefficient.

Figure 5 shows a comparison of our results with previous investigators' results. It is shown that heat transfer characteristics of our new surfaces have advantages over those of a Teflon coated surface [2, 3], an electroplated gold surface [4], an electroplated silver surface [5] and are approximately the same as organic promoter surfaces [6, 7].

NOMENCLATURE

a	length appearing in equation (4) [m]
E	modulus of elasticity [N m^{-2}]
h	heat transfer coefficient [W m^{-2} K^{-1}]
Q	heat flux [W m^{-2}]
Δt	temperature difference between two measuring points [K]
T	degree of surface subcooling [K]
$T1$	temperature of first measuring point [K]
T_s	surface temperature [K]
T_v	steam temperature [K]
V	flow rate of coolant [m^3 h^{-1}].

Greek symbols

δ	distance between two measuring points [m]
δ_1	distance from first measuring point to surface [m]
λ	thermal conductivity [W m^{-2} K^{-1}]
σ	surface energy [J m^{-2}].

5. THE CHARACTERISTICS OF THE ALLOY SURFACES

The alloy elements implanted in the surface layer of copper exist in the state of solid solution. There is no obvious interface between the alloy layer and the copper body.

The alloy surfaces have the following characteristics:

(1) The alloy layer is not easy to strip off, so dropwise condensation can be maintained for a long time.

(2) The thickness of the alloy layer is only about several thousand ångströms, so additional heat resistance is negligible.

According to characteristics of the alloy surfaces and reasonable cost, we conclude that the alloy surfaces have an advantage over other surfaces of maintaining dropwise condensation.

6. DISCUSSION

It was found that, with the dose of ion-implantation increasing, the crystalline surface layer of copper was

Table 1. Optima of ion-implanted dose and ion-implanted energy

No.	Element	Dose (ion cm^{-2})	Energy (keV)
1	He	5×10^{17}	70
2	Ar	5×10^{17}	70
3	N	5×10^{17}	80
4	H	6×10^{17}	60

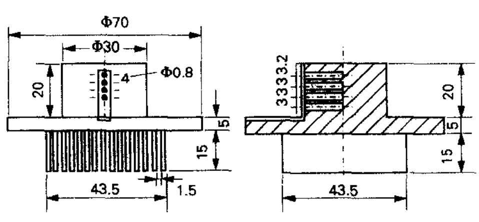

FIG. 1. Condensing block.

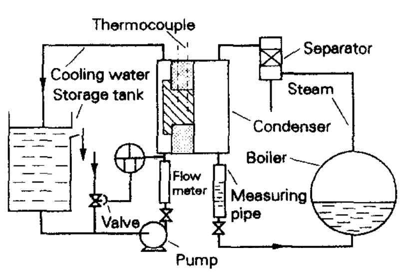

FIG. 2. Experimental loop.

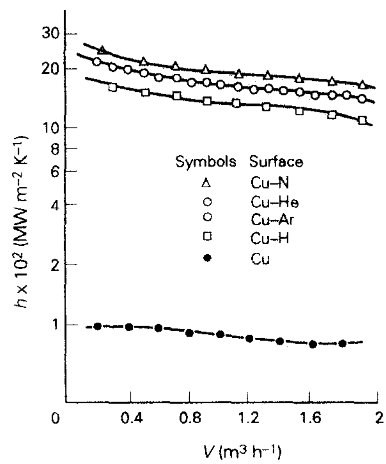

FIG. 3. The effect of flow rate of cooling water on heat transfer coefficient.

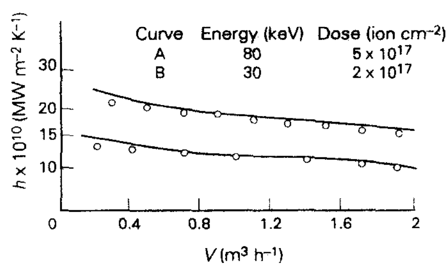

FIG. 4. The effect of N^+-implanted conditions on heat transfer coefficient.

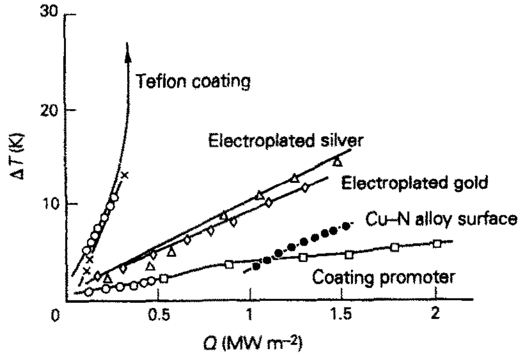

FIG. 5. Comparison of our surface with other surfaces for heat transfer characteristics.

transformed into the amorphous state. The relation between modulus of elasticity and surface energy is [8]

$$r = \frac{Ea}{4\pi^2} \quad (4)$$

where r is the surface energy, E the modulus of elasticity, and a a constant.

Because the modulus of elasticity of the amorphous state is about 20–30% lower than that of the crystalline state, from the above equation, the amorphous surface layer has a lower surface energy, compared with the crystalline surface layer. The formation of the amorphous state is an important reason why dropwise condensation was formed on the new surfaces.

7. CONCLUSION

(1) Excellent steam dropwise condensation was obtained on the surfaces of copper alloys: Cu–He, Cu–Ar, Cu–N, and Cu–H.

(2) The characteristics of alloy surfaces have advantages over other surfaces for maintaining dropwise condensation.

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MATERIAUX DE SURFACE POUR LA CONDENSATION EN GOUTTES OBTENUS PAR LA TECHNOLOGIE D'IMPLANTATION D'IONS

Résumé—Une nouvelle méthode d'obtention de la condensation en gouttes est présentée en préparant des alliages de surface qui possèdent une faible énergie de surface. Quatre sortes d'alliages de cuivre sont faites par la technologie d'implantation d'ions. La condensation de vapeur permanente en gouttes est formée sur les quatre surfaces. On analyse les caractéristiques des surfaces d'alliages.

HERSTELLUNG EINER OBERFLÄCHE FÜR TROPFENKONDENSATION MIT HILFE DER IONEN-IMPLANTATION

Zusammenfassung—Es wird eine neues Verfahren zur Herstellung von Oberflächen für die Tropfenkondensation vorgestellt. Derartige metallische Oberflächen sind durch besonders geringe Oberflächenenergie gekennzeichnet. Mit Hilfe des Verfahrens der Ionen-Implantation werden vier unterschiedliche Oberflächen aus einer Kupferlegierung hergestellt. Auf diesen vier Oberflächen bildet sich stationäre Tropfenkondensation von Wasserdampf aus. Die charakteristischen Eigenschaften dieser Oberflächen werden analysiert.

КАПЕЛЬНАЯ КОНДЕНСАЦИЯ НА ПОВЕРХНОСТЯХ, ИЗГОТОВЛЕННЫХ С ИСПОЛЬЗОВАНИЕМ ТЕХНОЛОГИИ ВНЕДРЕНИЯ ИОНОВ

Аннотация—Описывается новый метод капельной конденсации, осуществляемый путем приготовления сплавов с низкой поверхностной энергией. С использованием технологии внедрения ионов получены четыре вида сплавов меди. На этих четырех поверхностях возникает устойчивая капельная конденсация водяного пара. Анализируются характеристики данных поверхностей.