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Wetting properties of liquid lithium on lithium compounds

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HIGHLIGHTS

- Contact angles of liquid lithium and Li_3N, Li_2O, Li_2CO_3 were measured.
- Liquid lithium wets lithium compounds at relatively low temperatures: Li_3N at 257 °C, Li_2O at 259 °C, Li_2CO_3 at 323 °C.
- Li wets Li_2O and Li_3N better than previously measured fusion-relevant materials (W, Mo, Ta, TZM, stainless steel).
- Li wets Li_2CO_3 better than most previously measured fusion-relevant materials (W, Mo, Ta).

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ABSTRACT

Liquid metal plasma facing components (LMPFC) have shown a potential to supplant solid plasma facing components materials in the high heat flux regions of magnetic confinement fusion reactors due to the reduction or elimination of concerns over melting, wall damage, and erosion. To design a workable LMPFC, one must understand how liquid metal interacts with solid underlying structures. Wetting is an important factor in such interaction, several designs of LMPFC require liquid metal to wet the underlying solid structures. The wetting of lithium compounds (lithium nitride, oxide, and carbonate) by 200 °C liquid lithium at various surface temperature from 230 to 330 °C was studied by means of contact angle measurements. Wetting temperatures, defined as the temperature above which the contact angle is less than 90°, were measured. The wetting temperature was 257 °C for nitride, 259 °C for oxide, and 323 °C for carbonate. Surface tensions of solid lithium compounds were calculated from the contact angle measurements.

1. Introduction

Liquid lithium is considered for use in plasma-facing components (PFC) of fusion devices for several reasons. Lithium has a low atomic number, a low melting point of only 179 °C, a high boiling point, and high surface tension. Liquid surfaces allow the avoidance of numerous problems that solid PFCs face due to intense heat loads observed in fusion installations. Lithium has also been shown to positively affect fusion plasmas, leading to a decrease in recycling and increase of the confinement time [1–5].

There are a number of PFC systems of different designs that use liquid lithium, such as capillary porous systems (CPS) [5–7] and liquid metal infused trench (LIMIT) systems [8,9]. Liquid lithium in these schemes is supported by a solid material, and wetting of the substrate by lithium is an important criterion required for many of the proposed designs to work. The CPS design is reliant on capillary forces to function and thus requires lithium to wet the CPS material. The LIMIT design relies on lithium flow in trenches, therefore lithium must wet the surfaces of channels. If lithium is used in upside-down or vertical elements, it must also wet their surfaces.

Lithium's ability to wet typical fusion-relevant materials, such as tungsten, molybdenum, TZM, stainless steel, and others has been studied. Lithium is very chemically active, and it reacts with all atmospheric gases and hydrogen, producing solid compounds with high melting temperatures [10–13]. It's impossible to guarantee that during operation, or in shutdown phase, when an installation is vented for maintenance purposes, such as to change diagnos-

Abbreviations: PFC, plasma-facing components; CPS, capillary porous system; LIMIT, liquid metal infused trench.

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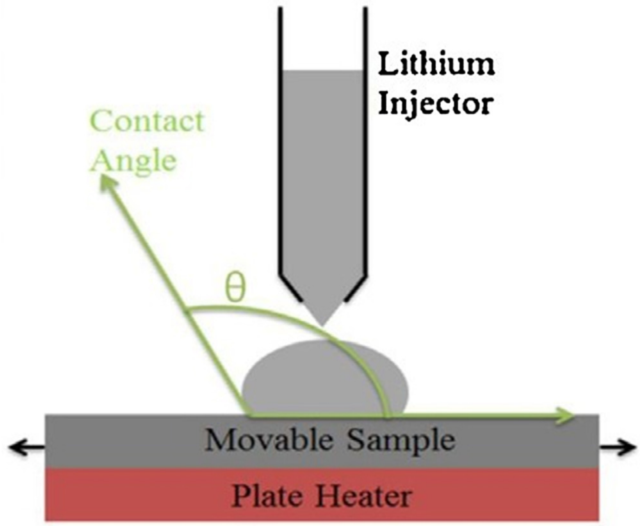

Fig. 1. Principal experimental scheme. Lithium droplets kept at a constant temperature are deposited onto a heated movable surface using mechanical lithium injector.

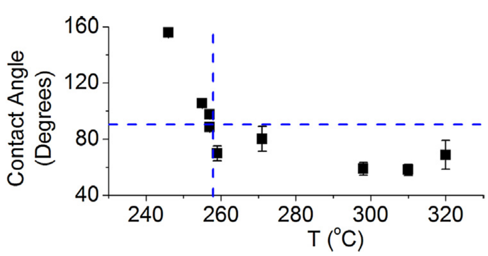

Fig. 2. Contact angles of 200 °C lithium drop on lithium nitride. Blue dashed line indicates wetting point temperature. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tics, lithium won't come in contact with atmospheric air. It's also possible that it'll form compounds with residual gas components. Therefore, it is important to know how lithium wets the surfaces of solid lithium compounds.

In this work, wetting of solid lithium compounds formed during interaction with primary atmospheric gases (lithium nitride, lithium oxide and lithium carbonate) by liquid lithium was studied, and wetting temperatures were determined. The dependence of the surface tension of lithium nitride, oxide and carbonate on temperature was also calculated. Contact angles and wetting temperatures were estimated for the case that the temperature of the lithium and the substrate are equal.

2. Basics

Wetting of flat solid surfaces is described by Young's equation

$$\gamma_S = \gamma_{SL} + \gamma_L \cos\theta \quad (1)$$

where γ_S, γ_L, are surface tensions (energies) of the solid being wetted and the wetting liquid respectively, γ_{SL} is the surface tension at the interface between the solid and the liquid, and θ is the contact angle. Liquid is considered to wet the solid surface if $\theta < 90°$. It can be shown [14,15] that γ_{SL} is a function of γ_S, γ_L, and can be empirically described as

$$\gamma_{SL} = \gamma_S + \gamma_L - 2\sqrt{\gamma_S\gamma_L}e^{-\beta(\gamma_S-\gamma_L)^2} \quad (2)$$

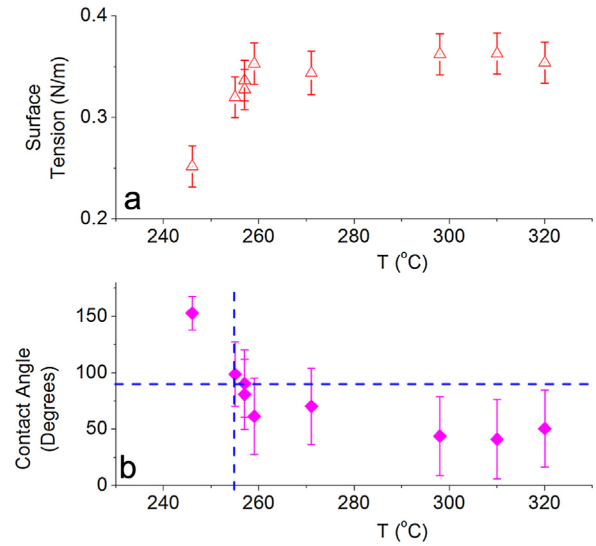

Fig. 3. Temperature dependences calculated from experimental contact angle measurements (Fig. 1): (a) surface tension of lithium nitride at different temperatures, (b) contact angles of lithium on lithium nitride assuming that the temperature of lithium and lithium nitride are the same; blue dashed line indicates wetting temperature for this case. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

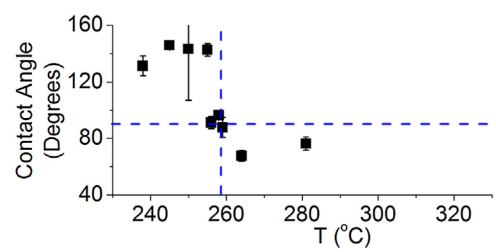

Fig. 4. Contact angles of 200 °C lithium drop on lithium oxide. Blue dashed line indicates wetting temperature. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

where $\beta = 123.4\left(\mathrm{m/N}\right)^2$ is an empirical constant. When combined with Young's Eq. (1), it results in the equation

$$\cos\ \theta = -1 + 2\sqrt{\frac{\gamma_S}{\gamma_L}}e^{-\beta(\gamma_S-\gamma_L)^2} \quad (3)$$

that can be used to obtain γ_S if values of γ_L and θ are known.

Both γ_S and γ_L depend on the temperature. For a given liquid temperature, wetting is possible above a certain temperature of the solid surface, called the wetting temperature. Dependence of the surface tension of liquid lithium on the temperature is described in several literature sources (e.g. [16,17]), though there is no good agreement between them. In this work we use the following equation from Ref. [17].

$$\gamma_L\left[\frac{N}{m}\right] = 0.43898 - 1.844\cdot 10^{-5}T\,[K] - 1.3220\cdot 10^{-7}T^2 + 3.744\cdot 10^{-11}T^3 \quad (4)$$

3. Experimental

Experiments were performed using the MCATS installation as in Ref. [18]. The experimental scheme is shown in Fig. 1. As Li is chemically active, vacuum conditions were improved, and residual gas pressure was reduced to 4×10^{-5} Pa. The gas-backed lithium