

Wetting of molten Bi–Sn alloy on amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$

G.F. Ma^{a,b}, N. Liu^{a,b}, H.F. Zhang^{a,*}, H. Li^a, Z.Q. Hu^a

^a Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China

^b Graduate School of the Chinese Academy of Sciences, Beijing 100039, China

Received 23 November 2006; received in revised form 7 February 2007; accepted 10 February 2007

Available online 20 February 2007

Abstract

Wetting behavior of amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate by molten Bi–Sn alloy was investigated by sessile drop technique. Liquid–solid reaction and the crystallization reaction occur in the reactive zone of the liquid/solid interface. We found that the equilibrium contact angle on amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate does not decrease monotonically with increasing temperature. Pre-annealing of amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ made the equilibrium contact angle increase with the increase of the pre-annealing temperature. We propose that the crystallization reaction in the interface provides an additional driving force for the observed spreading process. By analyzing wetting kinetics, three wetting stages were identified in the wetting process.

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Keywords: Liquid–solid reaction; Bi–Sn alloy; Crystallization reaction; Amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$; Wetting kinetics

1. Introduction

Wetting properties of liquid alloys on solid substrates are important in various practical applications, such as brazing, soldering, plasma spraying, moulding of steel and alloy [1–5]. It is well known that the wetting of liquid on crystalline substrates has been studied extensively since early 1990s [6,7]. Amorphous alloy usually possesses high strength, soft magnetic properties and good corrosion resistance, which are superior to the corresponding crystalline alloy. Hence they are considered to have many potential applications as advanced engineering materials [8,9]. However, to the authors' knowledge, few specific studies have been carried out on the wetting of liquid alloy on metallic glass substrate. With further development of metallic glasses, it is necessary to study the wetting behaviors of amorphous alloys both from the fundamental and practical interest.

When a liquid drop is placed on a solid substrate, the drop usually spreads with time; i.e., the radius of the drop increases, and the contact angle of the drop decreases. The kinetics of the spreading of a liquid drop on a solid surface can be classified into two types [10,11]: (a) nonreactive (class I), where the kinetics are determined solely by the constant liquid and solid properties,

normally the viscosity and interfacial energy, and by gravity or thermal effects if these apply; (b) reactive (class II), where chemical effects are involved and the liquid reacts with the substrate, producing changes in the system during the spreading process.

Here, we present the result of reactive spreading behavior of molten Bi–Sn alloy on an amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ alloy. To investigate reactive spreading behavior in relatively large temperature, 43Sn–57Bi (in wt.%) alloy with low melting point and amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ (in at.%) alloy with high glass transition temperature T_g were selected as experiential materials. The effect of temperature on the interfacial reactions and contact angle are examined.

2. Experimental procedure

The eutectic alloy composition (43Sn–57Bi wt.%) was prepared by induction melting in high purity argon atmosphere (99.99%). Then the alloy was cut into about 50 mg pieces. Amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ ribbon with $\sim 35 \mu\text{m}$ thickness was cut into small substrates of $20 \text{ mm} \times 20 \text{ mm}$ and then polished. Amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ ribbons were annealed for 30 min at different temperature under vacuum furnace. Fig. 1 shows the X-ray diffraction (XRD) pattern of $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ alloys. Before being subject to measurements, both substrates and pieces of Bi–Sn alloy were cleaned in acetone.

Wetting examinations were performed by the sessile drop method under vacuum (10^{-3} Pa) at various temperatures. While the desired operation temperature was achieved, wetting angles were recorded photographically using back lighting at various times until an equilibrium angle could be recorded. After completion of the sessile drop experiments, the solidified samples were sec-

* Corresponding author. Tel.: +86 24 23971785; fax: +86 24 23891320.
E-mail address: hfzhang@imr.ac.cn (H.F. Zhang).

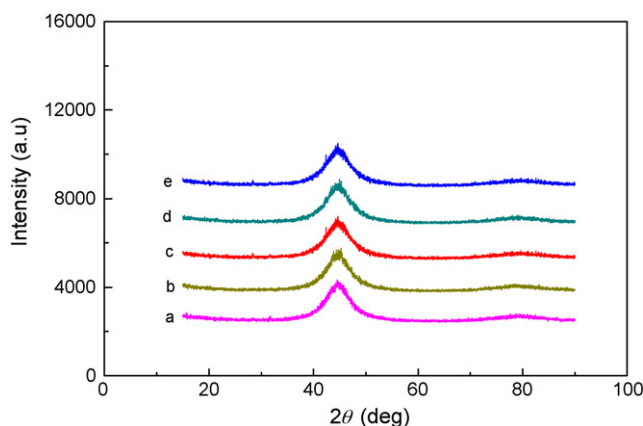


Fig. 1. X-ray diffraction patterns for the $\text{Fe}_{78}\text{Si}_9\text{B}_{13}$ substrate annealed at various temperatures: (a) 473 K; (b) 523 K; (c) 573 K; (d) 623 K; (e) 673 K.

tioned to examine the interface between molten Bi–Sn alloy and amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$. Cross sections were polished and examined using the scanning electron microscopy (SEM). The chemical compositions of any interface compounds were determined using an attached energy diffraction spectrum (EDS). The unreacted molten alloy of the wetting experiment specimens was etched off with H_2O_2 –acetic acid solution to reveal the intermetallic compounds formed at the interface. The exposed compound layer was further characterized using X-ray diffraction.

3. Results and discussion

3.1. Intermetallic compound

For reactive wetting systems, wetting process usually occurs with extensive chemical reaction, accompanied by the formation of a new solid compound at the metal/substrate interface. Fig. 2 presents two representative SEM micrographs for cross section of the molten Bi–Sn/amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ ribbon examined at respective 573 and 623 K. In both cases, an intermetallic compound exists at the interface over the entire contact area. EDS analysis shows that reaction layer is consisted of iron, tin and silicon. The presence of silicon in the layer suggests that the crystallization reaction may occur in the interface between Bi–Sn alloy and amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate. Fig. 3 shows the X-ray diffraction patterns of amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ free surface and Bi–Sn/amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ interface held at 573 K

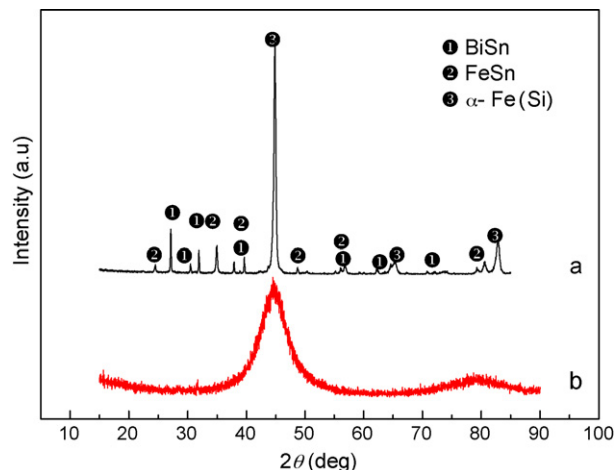


Fig. 3. X-ray diffraction patterns of (a) the interface of Bi–Sn/amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ after holding the sample at 573 K for 30 min and (b) $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ free surface.

for 30 min. It is found that there are diffraction peaks of FeSn and crystallization product α -FeSi in reactive layer of interface besides diffraction peaks of Bi–Sn. In contrast, there is a broad diffraction peak in $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ free surface, and no sharp peaks corresponding to a crystalline phase are observed. Hence, it suggests that the crystallization reaction may occur in the spreading process of molten Bi–Sn alloy on amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$. In the wetting process of molten Bi–Sn alloy on amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate, the metastable structure of the amorphous alloy is changed due to the reaction of the active Sn atoms in the molten Bi–Sn alloy and the active Fe atoms in amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$. Thus, the residual atoms in amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ become even more unstable and tend to be crystallized.

3.2. Wetting angle

Fig. 4 shows the profile for the equilibrium contact angles of molten Bi–Sn alloy on amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate as a function of temperature. In great contrast to the evolution of the equilibrium contact angle with respect to polycrystalline alloy substrate, the equilibrium contact angle for the amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate does not decrease monotonically with increasing temperature: the mean equilibrium contact angle

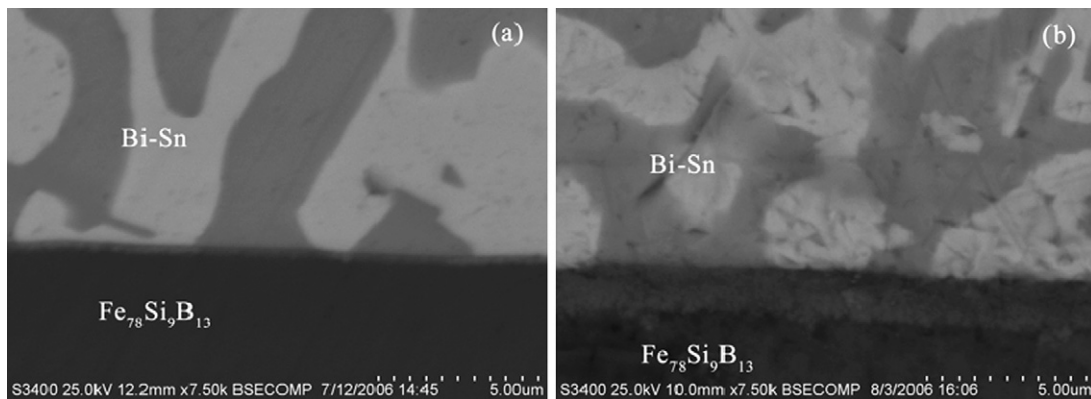


Fig. 2. SEM micrographs of the interface between molten Bi–Sn and amorphous $\text{Fe}_{78}\text{B}_{13}\text{Si}_9$ substrate after heating for 30 min (a) 573 K; (b) 623 K.

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