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Oxidation behavior of a γ-TiAl-based alloy implanted by silicon and/or carbon

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Abstract

A study has been made of isothermal oxidation behavior of a γ-TiAl-based alloy, Ti–48Al–1.3Fe–1.1V–0.3B (at.%), implanted with silicon and/or carbon ions at 1173 K, C + Si double implantation and following annealing at 1123 K for 10.8 ks. The isothermal oxidation was tested at 1173 K for 349.2 ks in air. Si or C implantation was carried out with a dose of 3.0×10^{21} ions/m^2 and at the acceleration voltage of 50 and 70 kV. As-implanted specimen and the specimen oxidized under specified conditions were characterized by Auger electron spectroscopy (AES), X-ray diffractometry (XRD) and scanning electron microscopy (SEM).

High-temperature Si implantation at 1173 K shows better oxidation resistance than that implanted at room temperature (RT) for the long-term oxidation. The C introduction by C + Si double implantation weakened the beneficial effect of Si, and the following annealing improved its oxidation resistance. Si doping in the TiAl alloy could facility the Al_2O_3 formation in the early stage of the oxidation through the enhancement of the Al activity, and C doping is harmful because of a porous oxide scale. From this study, it is indicated that high-temperature implantation at 1173 K is effective to thicken the Si-modified layer and thus, a strong and long-term Si modification effect. No cooperation effect of C and Si can be observed for C + Si double implantation to intensify the Si beneficial effect.

Keywords: Titanium alumindes; Ion implantation; High-temperature oxidation; Oxide scale

1. Introduction

Researches on the improvement of oxidation resistance of γ-TiAl-based alloy were intensively conducted by considering its poor oxidation performance above 1100 K [1–7]. In the field of surface protection, ion implantation modifies oxidation property, because it can precisely dope various elements into materials surface with good repeatability. For γ-TiAl-based alloy, implantation of Nb, W, Si, Al, etc. with the appropriate dose shows the beneficial effect on its oxidation resistance [2–4]. The way to perform the implantation also is important on such effect, for example, implantation at high temperature could deepen the modified layer and thus enhance the doping effect [5]; double ion implantation sometimes is more effective [6]. Post-implantation treatment, such as annealing was proved to be positive as well [7]. Above results indicated that ion implantation was not only a tool to screen suitable elements and provide useful information for alloying addition for the improvement of the oxidation resistance of γ-TiAl-based alloy, it also could be used directly as an effective surface protection in terms of real application.

Silicon implantation at room temperature (RT) improved the oxidation resistance of γ-TiAl-based alloy considerably [4]. In this study, C + Si double implantation, Si implantation at 1173 K and post-implantation annealing were conducted on a γ-TiAl-based alloy, and their influence on the oxidation behavior of this alloy were examined. On the basis

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of the experimental results, the effects of the implanted element Si and C as well as the implantation process were proposed.

2. Experimental

2.1. Specimen

The ingot of the investigated TiAl was produced by Ar-arc skull melting and annealed at 1373 K for 86.4 ks in a vacuum for homogenization. The chemical composition of this alloy is Ti–48Al–1.3Fe–1.1V–0.3B (at.%). X-ray diffractometry (XRD) examination revealed that this alloy is composed mostly of γ-TiAl together with few α_2-Ti_3Al. Specimens with the size of $\approx$15 mm $\times$ 10 mm $\times$ 2 mm were cut from the ingot. For ion implantation, the specimen surface was ground with a series of SiC paper of up to $1000^{\#}$ and then polished with alumina powders of 0.3 μm in size to mirror finish. Finally, the specimens were ultrasonically washed in acetone and ethanol bath.

2.2. Ion implantation and oxidation test

High-temperature Si implantation was conducted at 1173 K with a dose of 3.0×10^{21} ions/m^2 and at an acceleration voltage of 50 kV. C + Si double implantation was carried out by C first implantation with a dose of 3.0×10^{21} ions/m^2 at 70 kV and then Si implantation at 50 kV with the same dose at room temperature. For comparison, single C and Si were implanted at room temperature (RT) with a dose of 3.0×10^{21} ions/m^2 at an acceleration voltage of 50 kV. Only two large surfaces of 15 mm $\times$ 10 mm of each specimen were implanted.

To check the effect of the post-implantation treatment, specimens treated by C + Si double implantation were annealed at 1123 K for 10.8 ks in vacuum.

The long-term isothermal oxidation tests were carried out at 1173 K for up to 349.2 ks in static laboratory air using a thermobalance that can continuously record the mass gain. In order to determine the diffusion process of the doping element during oxidation, short-term isothermal oxidation of 0.9, 1.8 and 3.6 ks for specific specimen was also performed. At the end of the test, the specimen was furnace-cooled.

2.3. Metallographic examinations

Distribution of the doping element in the as-implanted layer and the oxide scale formed by short-term oxidation was examined by Auger electron spectroscopy (AES). The phase composition was identified by X-ray diffractometry (XRD) using Cu Kα radiation at 40 kV and 30 mA, and the θ–2θ method was performed. The surface and cross-section morphology of the scale were observed by scanning electron microscopy (SEM) at an acceleration voltage of 15 kV.

3. Results

3.1. Isothermal oxidation kinetics

The effects of C + Si double implantation, post-implantation annealing and Si implantation at 1173 K on the oxidation behavior of the investigated γ-TiAl-based alloy are revealed in Fig. 1 by the isothermal oxidation kinetic curves tested at 1173 K in air. The error for the mass gain in Fig. 1 is 10^{-3} kg/m^2. Si implantation at RT improved the oxidation resistance significantly and single C doping is negative (Fig. 1a). The oxidation resistance of the TiAl alloy implanted by both C and Si is poorer than that of only Si implantation. Although the post-implantation annealing at 1123 K for 10.8 ks on C + Si double implantation decreased its oxidation rate notably, the detrimental effect of C in this case is still notable. This result is different from that of C + Nb double implantation in TiAl alloy, in which the introduction of C enhanced the beneficial effect of Nb and thus, a considerable improvement of the oxidation resistance was obtained [6]. High-temperature Si implantation at 1173 K lowered the mass gain relative to that implanted at room temperature after long-term oxidation (Fig. 1b).

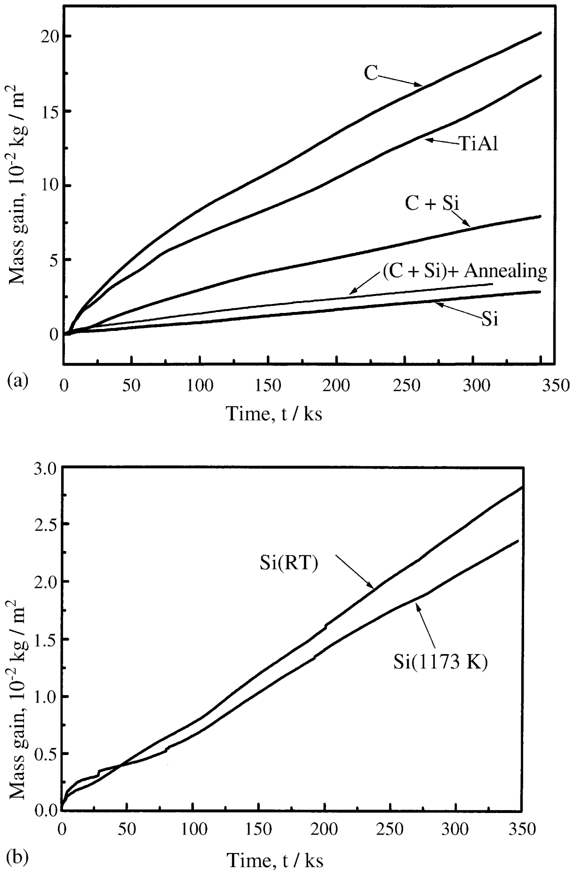

Fig. 1. Isothermal oxidation kinetics at 1173 K in air for the TiAl alloy treated by: (a) various conditions and (b) Si implantation at RT and 1173 K.