Study of the corrosion behaviors of 304 austenite stainless steel specimens exposed to static liquid lithium at 600K

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Abstract

Investigation of corrosion behavior of stainless steel served as one kind of structure materials exposed to liquid lithium (Li) is one of the keys to apply liquid Li as potential plasma facing materials (PFM) or blanket coolant in the fusion device. Corrosion experiments of 304 austenite stainless steel (304SS) were carried out in static liquid Li at 600 K and up to 1584 hours at high vacuum with pressure less than 4×10^{-4} Pa. After exposure to liquid Li, it was found that the weight of 304SS slightly decreased with weight loss rate of 5.7×10^{-4} g/m²/h and surface hardness increased by about 50HV. Lots of spinel-like grains and holes were observed on the surface of specimens measured by SEM. By further EDS, XRD and metallographic analyzing, it was confirmed that the main compositions of spinel-like grains were M₂₃C₆ carbides, and 304SS produced a non-uniform corrosion behavior by preferential grain boundary attack, possibly due to the easy formation of M₂₃C₆ carbides and/or formation of Li

compound at grain boundaries.

1. Introduction

As a candidate material of plasma facing components (PFCs) for fusion devices, liquid Li has been got more and more attentions in recent decades. Li as an active metal with a low atomic number and is used as a trapper of residual gas for that it can react easily with H_2O , O_2 , H_2 , CO_2 and N_2 in fusion device, which can reduce effectively H isotopes recycling and decrease impurities content in the plasma [1-6]. Moreover, the flowing liquid Li wall in fusion device can continuously remove high particle and heat fluxes from plasma bombardment and self-heal the damaged wall materials [7, 8]. By using liquid Li limiters (LLs) in fusion device, the dramatical improvements of plasma performance have been obtained. For example, in FTU, T-11M and CDX-U devices, plasma discharges with lower impurity control and higher confinement were achieved by using LL [9-14]. Some promising results were also achieved in HT-7 and EAST by using a LL [7, 15-22]. It was found that the H recycling was reduced by 20–30%, the particle confinement time increased by a factor of 2, the impurity emission intensity was decreased by about 10–20% and the energy confinement time was increased by 20%.

Liquid Li is also considered as a candidate material of blanket coolants and tritium breeders for fusion reactors. In these systems with liquid Li, most of structure materials of Li tanks and feeding pipes are stainless steel. The low activation ferritic steels and 321SS were used as the structure materials of liquid Li loops in IFMIF and IPPE. 316LSS and 304SS were used as the structure materials of liquid Li loops in JAEA and Osaka University [23-24]. Therefore, the wide application of liquid Li in fusion reactors requires a critical assessment of the compatibility of liquid Li with

stainless steel structural materials. Some corrosion experiments of steel materials in liquid Li have been performed for different purposes. The compatibility of JLF-1 (a reduce activation ferrite/martensitic steel) and liquid Li were studied in static and flowing liquid Li [25-30]. The selective dissolution of W, Cr and C was found for the JLF-1 in static liquid Li; then the phase transformation from martensite to ferrite was observed at 973K due to C depletion. The weight loss of JLF-1 in static liquid Li at 873K was larger than that at 773K. The weight loss of JLF-1 in flowing Li was one order of magnitude larger than that in static one. To investigate the mass transferring of elements in liquid Li, *Tortorelli* [31] exposed the Fe-12Cr-1MoVW steel to thermally convective Li for 696 hours and found that Cr tended to be transported to the intermediated temperature part of the loop, but Ni tended to be transported to the coldest part of the loop. It was also found that some impurities, such as N, have high solubility in Li, which can enhance drastically the corrosion aggressiveness of Li [32-35].

As mentioned above, the corrosion behaviors of structural materials in liquid Li depend seriously on the experiment conditions. Several LLLs on HT-7 [16-20] and EAST [20-22] have been performed since 2009. Two kinds of static liquid lithium limiters with free surface and capillary-pore system (CPS) configuration were successively utilized in HT-7 in 2009 and 2011 with pressure less than 4×10^{-5} Pa. The structural materials used for the limiters base, pipes and Li tanks were 304SS or 316LSS, and the temperature of liquid Li was 500~700 K. To further guide the design and application of the components with liquid Li in EAST device, it is very necessary to study the corrosion behaviors and mechanisms of the stainless steel exposed to liquid Li at operation condition. Furthermore, it is demonstrated from the experimental results of wettability that the critical wetting temperature of liquid Li on

SS was about 600K [36]. In the present paper, the corrosion behavior of 304 SS in static liquid Li at 600K was investigated in detail.

2. Experimental setup

All the corrosion experiments were conducted in a static liquid Li testing device where it can be heated to more than 600 K and pumped to high vacuum condition ($< 4 \times 10^{-4}$ Pa) for suppressing Li interact with impurities. Fig. 1 shows the schematic diagram of static liquid Li testing device. The primary react vessel is a vacuum cylinder one with an inner diameter of 250mm and a height of 330 mm. A sampling system consists of a guide rod and a bellow with the diameter of 35mm and the length of 320 mm. By the bellow driving, it can push or pull the sample into or out of liquid Li. The vacuum system includes a turbo-molecular pump to get a high vacuum, a PCG vacuum gauge to monitor the vacuum, a leak detector to monitor the leak rate of vessel real-time. To protect the device safety, the function of safety interlock and protection was designed. If the react vessel's pressure is higher than 10Pa, the VED electromagnetic valve (Fig.1 (8)) will open and electromagnetic valve (Fig.1 (9)) will close, at the same time argon will fill to device upto 1 atm. In addition, A DC power, three heater strips and two thermocouples constitute the heating and temperature measurement system. The viewing system consists of a Network Camera to monitor the whole condition of the experiment, an Ø100 observation window on the top of vessel to observe the condition of liquid Li and specimens. The test vessel and fixture for loading the specimens are also made of 304SS to avoid addition mass transfer.

The specimens, with composition (wt% analyzed by chemical method): 17.07Cr, 2.4Mo, 1.00Mn, 10.31Ni, 0.026C, 0.34Si, 0.24Cu, 0.21Co, 0.045Al, 0.064S, and Fe as balance, is coupon-type with a size of 10mm (W) $\times$ 15mm (L) $\times$ 1mm (T). The

surfaces of the specimens were mechanically polished before the experiment. Metal Li was supplied in ingots and the initial impurity contents were also listed in Table 1. Before test, six specimens were hung on the hooks in 20 millimeter off the bottom of test vessel, as show in Fig. 1. Then turned on the turbo-molecular pump to get a high vacuum in order to suppress the influence of impurities, then heated the test vessel to 380°C and kept about 12 hours. After finishing leak detection and vessel gas release, about 900g Li (The depth of liquid Li was about 35mm when Li melted, all specimens were immersed) was placed into test vessel with Ar protection, and then the corrosion test started. The test vessel was heated up to 330°C (about 600 K). The vacuum was less than 4.0×10^{-4} Pa and the measured vessel leak rate was less than 1×10^{-10} Pam³/s.

The corrosion experiments were conducted 600K from 0h to 1584 hours. After exposure, every 264 hours we turned off the heater to cool the device to ambient temperature. The specimens were removed from test vessel in Ar atmosphere. And then they were successively cleaned by flowing water and high purity alcohol to remove the remnant Li and get clear specimens. It can minimized the effect of a part of hydrogen be absorbed in the specimens and no degradation effects on the mechanical properties of specimens [30].

The corrosion rate was evaluated by means of weight measurement using electro-balance with an accuracy of 0.01mg before and after exposing to the liquid Li. A Sirion200 scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) and X-ray diffraction analysis (XRD, Cu K α radiation) were used to characterize the microstructural and compositional changes of the corroded surface. The Vickers hardness was measured as a function of time under a load of 500gf with a loading time of 15 seconds. For each specimen, it would measure 5 points and then calculate the average value of 5 measurements to evaluate the hardness change. The

metallurgical analysis was performed with the aid of an optical microscope, the specimens were ground using silicon carbide papers with a grids order of 800, 1200 and 2000 and mechanically polished by alumina powder with a diameter of 0.3 μ m and 0.05 μ m and then chemical etched in aqua regia about 3~5 seconds.

3. Results and discussion

3.1. Weight loss of the 304SS specimens

The corrosion behaviors were evaluated by measuring the weight loss of the 304SS specimens exposed to static liquid Li for different time. The weight loss per square meter (ΔW) was calculated by the equation $\Delta W = (m_1 - m_0)/S$, where S is the surface area of each specimen, m_1 and m_0 are the weights of corroded and initial specimens, respectively. The weight loss for 304SS specimens at different time were shown in Fig. 2. The results indicate that the weight loss for 304SS specimens showed a power law trend (power of 1/2) with time. After being dipped into liquid Li for 1584 hours, the weight loss rate was about 5.7×10^{-4} g/m²/h. The weight loss of 304SS specimens was about 0.895 g/m², equivalent to a thickness of 113 nm upon an assumption of 7.93 g/cm³ as the density of 304SS specimens.

It's well known that the alloy elements, such as C, Cr, Fe, Ni and Mn, can be dissolved easily in liquid metal [30, 37-39]. The weight loss of 304SS specimens in the liquid Li can be attributed to the dissolution of C, Cr, Mn, Fe and Ni in the alloy and the formation of corrosion products on specimen surface. Firstly, the specimen's mass was badly lost due to elements in the alloy dissolved in liquid Li with a constant dissolution rate. Then, the corrosion products were made of dissolved elements on the surface. Finally, the specimen's mass loss tended to constant because of the dissolution of elements in alloy was almost saturated in bulk Li, or the corrosion products covered all surface to form a saturated layer of dissolved elements in liquid

Li near the specimen's surface, as described below. Moreover, the concentration and mass of C and Mn in 304SS are much less than those of Fe, Cr and Ni, therefore the contribution from the C and Mn depletion on the mass loss is small.

3.2. Microstructure change of specimens

Fig. 3 shows the microstructures of 304SS specimens measured by SEM. Six surface morphologies after the corrosion tests from 0 to 1584 hours have been shown respectively. As shown in Fig. 3(a), the 304SS specimen without corrosion test exhibits many nicks on the surface because of mechanical processing. After exposure to liquid Li, the specimens' surface lost the metallic luster and showed a non-uniform brightness, indicating some inhomogeneous corrosion. Many corroded particles adhered to the specimens' surface and their numbers increased significantly after being tested for 1320 hours, which indicated that the extent of corrosion increases with corrosion time. At higher magnification, the appearance of the corroded particles are typically spinel-like, with the sizes of 1~2 μm , as shown in Fig. 4. One can expect the following two possibilities for the spinel-like structures: (1) large precipitates, and (2) corrosion products by Li. It was found the particles preferred to accumulate along the machining marks and grew up with time, as shown in Fig. 5, and finally they almost covered all surfaces. To uncover the compositions of particles in the corroded region, EDS surface analysis was performed to obtain the elements profiles. The results showed that the main component elements of particles were Cr, Fe and C, as Fig. 6(f) shown, its main composition was M_{23}C_6 (M: Cr, Fe). The XRD surface analysis was performed to obtain the elements profiles of specimen's surface, the Cr and Fe carbides were also observed on the surface, as shown in Fig.6 (e). Fig. 7 shows that the material of 304SS specimen being exposed to static Li at 600 K for 792 hours is single-phase of austenite. By metallographic examination, the 304SS specimens

demonstrated non-uniform corrosion morphology by liquid Li, and there existed a lot of grain boundaries which were just like bold black lines. It was found that the essence of bold black line was chromium-depleted zone, which means the corrosion specimens suffered from a typical corrosive attack due to the dissolution of Cr element near the grain boundaries in liquid Li. Both the metallographic examination and EDS analyses indicate that the intensive spinel-like particles on the surface of the specimens being exposed to liquid Li were large precipitates of $M_{23}C_6$, which probably resulted from the liquid Li penetration along grain boundaries. The solubility of C in liquid Li is much higher than Fe and Cr, as reported by *Natesan et al.* [39] and the C is assumed to be dissolved as Li_2C_2 at low concentration of N_2 [40]. The chemical reactions of $6Fe + Li_2C_2 \rightarrow 2Fe_3C + 2Li$ and $7.66Cr + Li_2C_2 \rightarrow 0.3333Cr_{23}C_6 + 2Li$ can occur on the surface of specimens, and these are the reactions for C depletion from the alloy to the surface facing the liquid Li. But the Gibbs-free energy of $Cr_{23}C_6$ (-65 KJ/mol) was lower than Fe_3C (10 KJ/mol) and Mo_xC at 600 K in liquid Li [26]. It illustrates that the Fe does not react with Li_2C_2 easily, because the reaction is not spontaneous. According to Fig. 6(e), it was also confirmed that the dissolved elements Fe and Cr could react with Li_2C_2 to form Fe and Cr carbides and even form complex products of $Cr_xFe_yC_z$ on the surface of 304SS specimen under this operation condition. As reported by *Qi Xu et al.* [27], the carbon potential in Li was controlled by forming Mo and Nb carbides on inner surface of the Mo and Nb crucible. From these results it can deduced that the carbon potential in Li could also be controlled by forming Cr carbide. Furthermore, the diffusion energy for Cr along grain boundary and in grains were 162~252 KJ/mol and 540 KJ/mol, respectively. Therefore, the formation of $Cr_{23}C_6$ on grain boundaries was easily.

Moreover, as shown in Fig. 6, a lot of holes were found on the specimens' surfaces

after being exposed to liquid Li, and their sizes became larger as increasing the test time. However, the area ratios of holes decreased with test time. After being dipped into liquid Li for 1584 hours, the area ratio of holes was about 55%. Fig. 6 (d) indicates that after exposed, parts of a porous but still adherent layer were observed on the attacked steel surface, and parts of surface were hardly damaged. Similar results have been obtained that the dissolution of carbides into liquid Li resulted in some holes near the surface during investigating the compatibility of static liquid Li and JLF-1 steel [26]. The phenomenon was also found in some corrosion tests on ferritic-martensitic steel in Pb-17Li under dynamic conditions at 480 °C up to 8000 hours [41]. The result of line scan across the cross-section measured on 304SS specimen after exposure time for 1584 hours was presented in Fig. 8. The figure revealed a depletion of Cr and Fe near the surface. The thickness of corrosion layer was about 2 μm which was deeper than the calculated value. This was mainly due to that the carbides precipitates were not removed from the specimens surface when measured the weight loss of specimens.

As confirmed by other experiments [33-35, 42], the formation of M_{23}C_6 carbides at grain boundaries favored the penetration of Li. The formation of M_{23}C_6 precipitates could enhance the dissolution of C, Fe, and Cr in the vicinity of the 304SS specimens' grain boundaries, which led to the matrix being dissolved much easier in these areas. The formation and mass transferring of Li compound also induce Li penetrating into the grain boundaries. Although the N concentration was not found in the specimens in the present study, the combination of a turbo-molecular pump was kept be operating to obtain a high vacuum. But there was about 0.0027 wt% N found in liquid Li. The solubility of N was higher than that of Cr and Fe in liquid Li at high temperature [32-33], and the dissolved N can react easily with Li and Cr or Fe to form some

corrosion products, such as Li_9CrN_5 and Li_3FeN_2 , at high-angle grain boundaries [42]. Li_9CrN_5 and Li_3FeN_2 have a tunnel-like structure, which can promote fast exchange of the elements and lead to the penetration of Li into grain boundaries in steels [30]. The corrosion products and covered Li were dissolved when the surface of 304SS specimen was cleaned with water. The porous but still adherent layer was appeared on surface and there was almost no corrosion products adhered on the surface.

3.3. Hardness change of specimens

To investigate the influence of Li corrosion on mechanical properties, Vickers hardness tests were carried out on the surface of specimens before and after the Li exposure. Fig. 9 shows the variation of hardness as a function of time after the specimens being dipped into static Li at 600 K under high vacuum conditions. The hardness of 304SS specimens without corrosion was about 185 HV. After exposure to liquid Li for 1584 hours, the hardness of 304SS specimens increased to 231 HV. It's also found that the hardness of 304SS specimens increased with the corrosion time. The area ratio of particles at the same time was also plotted in the figure. It's interesting that the hardness of 304SS specimens increases with the area ratio of precipitates.

In order to investigate the relationship between hardness of steel surface and area ratio of grains, the hardness on different surface positions was measured and compared, as shown in Fig. 10. The figure revealed that the hardness was higher at the positions covered by M_{23}C_6 grains. Combining with Figs. 9 and 10, it was quite clear that the grains play an important role in hardness, and the hardness of 304SS specimens increases with the increase of concentration and mass of grains on the surfaces. It's known that Cr is a C-trapper [43] and it can get C atoms from liquid Li

and reduce the C concentration in liquid Li; then the equilibrium of C in liquid Li will be broken, which further lead to the depletion of C in the specimens and the increase of the hardness. *Barker* and *Frankham* [44] investigated the effects of C and N on the corrosion resistance of typical 316SS specimens in liquid Li, and they also found the hardness of those 316SS specimens increased with the concentration of carbon. Moreover, the increase of hardness of 304SS specimens can be divided into two stages. The hardness increased fast before the corrosion time of 528 hours and the average hardness increase rate was about 0.429. From 528 to 1584 hours, the hardness increased slowly, and the increase rate of average hardness was about 0.005. In the first stage, C, Cr, Fe and Mo can be dissolved easily into liquid Li; and then the carbides of $M_{23}C_6$ type formed. In the second stage, the dissolution of Fe, Cr, Mn and C was almost saturated in bulk Li, or the saturated layer of dissolved elements formatted in liquid Li near the specimen's surface; the formation of $M_{23}C_6$ was difficult and less.

4. Conclusion

The compatibility of 304SS specimens with static liquid Li at 600k under high vacuum condition was investigated. It was found that

- (1) After 1584 hours exposure to liquid Li, the 304SS specimens exhibited a power law trend of weight loss with the exposure duration time, the weight loss was $\sim 0.895 \text{ g/m}^2$, equivalent to $\sim 113 \text{ nm}$ thickness of 304SS specimens.
- (2) Due to the dissolution of C, Cr, Fe and Mn into liquid Li, the porous corroded morphologies appeared on the surface of 304SS specimens.
- (3) 304SS demonstrated a non-uniform corrosion behavior by preferential grain boundary attack, due to the formation of $M_{23}C_6$ carbides and/or Li compound at

grain boundaries in favor of the Li penetration.

- (4) Due to the formation of $M_{23}C_6$ carbides on surface, the surface hardness of 304SS specimens had a slight increase after exposure to liquid Li.

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References

- [1] D.K. Mansfield, et al., Phys. Plasmas 3 (1996) 1892.
- [2] Z.Sun, et al., Fus. Eng. Des. 89 (2014) 2886.
- [3] J. Sánchez, et al., Nucl. Fusion 49 (2009) 104018.
- [4] R. Maingi, et al., Nucl. Fusion 50 (2010) 064010.
- [5] D.K. Mansfield, et al., Nucl. Fusion 41 (2001) 1823.
- [6] J.S. Hu, et al., Phy. Rev. Lett. 114 (2015) 055001.
- [7] J. Ren, et al., Phys. Scr. T159 (2014) 014033.
- [8] T.D. Rognlien., J. Nucl. Mater. 290–293 (2001) 312.
- [9] V. Pericoli-Ridolfini, Plasma Phys. Control. Fusion 49 (2007) S123.
- [10] V. Pericoli-Ridolfini, et al., Nucl. Fusion 47 (2007) S608–S621.

- [11] S.V. Mirnov, et al., Plasma Phys. Controlled Fusion 48 (2006) 821.
- [12] K. Ushigusa, et al., Fusion Eng. Des. 45 (1999) 137–144.
- [13] R. Kaita, et al., J. Nucl. Mater. 337 (2005) 872.
- [14] R. Majeski, et al., Nucl. Fusion 45 (2005) 519.
- [15] J.S. Hu, et al., Fusion Eng. Des. 85 (2010) 930.
- [16] G.Z. Zuo, et al., J. Nucl. Mater. 415 (2011) S1062.
- [17] Z. Sun, et al., J. Nucl. Mater. 438 (2013) S899.
- [18] G.Z. Zuo, et al., Fusion Eng. Des. 89 (2014) 2845.
- [19] X.C. Meng, et al., Acta Phys. Sin. 64 (2015) 212801.
- [20] J.S. Hu, et al., Fusion Eng. Des. 89 (2014) 2875.
- [21] J. Ren, et al., Rev. Sci. Instrum. 82(2015) 23504.
- [22] J.S. Hu, et al., Nucl. Fusion. 56 (2016) 046011.
- [23] H. Kondo, et al., J. Eng GasTurb.Power 133 (2011).
- [24] H. Kondo, et al., Nucl. Fusion. 51 (2011) 123008.
- [25] Qi. Xu, et al., Fusion. Sc. Technol. 52 (2007) 609.
- [26] Qi. Xu, et al., Fusion Eng. Des. 83 (2008) 1477.
- [27] Qi. Xu, et al., J. Nucl.Mater. 394 (2009) 20.
- [28] Masatoshi Kondo, et al., J. Nucl. Mater. 417 (2011) 1200
- [29] Masatoshi Kondo, et al., Fusion Eng. Des. 87 (2012) 1777
- [30] Y.F. Li, et al., J. Nucl. Mater. 443 (2013) 200.
- [31] P.F. Tortorelli, J. Nucl. Mater. 155-157 (1988) 722
- [32] R.J. Pulham, et al., J. Nucl. Mater. 115 (1983) 239
- [33] M. Kondo, et al., Fusion Eng. Des. 87(2012) 1777.
- [34] V. Tsisar, et al., J. Nucl. Mater. 417 (2011) 1205.
- [35] A. Kimura, et al., Fus. Eng. Des. 81 (2006) 909.

- [36] G.Z. Zuo, et al., Rev. Sci. Instrum. 85, (2014) 023506.
- [37] O.K. Chopra, et al., J. Nucl. Mater. 103–104 (1981) 651.
- [38] I.E. Lyublinski, et al., J. Nucl. Mater. 224 (1995) 288.
- [39] K. Natesan, et al., J. Nucl. Mater. 115 (1983) 251.
- [40] R.J. Pulham, et al., J. Nucl. Mater. 115 (1983) 239.
- [41] H. Glasbrenner, et al., J. Nucl. Mater. 283-287 (2000) 1332.
- [42] E. Ruedl, et al., J. Nucl. Mater. 116 (1983) 112.
- [43] M.A. Abdou, et al., Fus. Eng. Des. 54 (2001) 181.
- [44] M.G. Barker, et al., J. Nucl. Mater. 107 (1982) 218.

Table list

Table. 1 The initial impurities content of metal Li.

Element	Na	K	Ca	Fe	N	Si	Cl	Al	Ni	Cu
Max Content ration %	0.0045	0.0002	0.0015	0.003	0.0027	0.0020	0.002	0.001	0.002	0.001

Figures list

Fig. 1 The schematic diagram of static liquid Li testing device: 1. main react vessel; 2. sampling system; 3. Specimens; 4. turbo-molecular pump; 5. vacuum gauge; 6. leak detector; 7. pressure controller; 8. VED electromagnetic valve; 9. electromagnetic valve; 10. Argon; 11. Observation window

Fig. 2 The weight loss of 304SS versus exposure time in liquid Li at 600 K

Fig. 3 The microstructures of 304SS before and after being dipped into liquid Li at 600 K. (a) before test; (b) exposure to liquid Li for 264h; (c) exposure to liquid Li for 528h; (d) exposure to liquid Li for 792h; (e) exposure to liquid Li for 1320h; (f) exposure to liquid Li for 1584h.

Fig. 4 The spinel-like appearance of particles

Fig. 5 The evolution of particles versus exposure time: (a) exposure to liquid Li for 264h; (b) exposure to liquid Li for 528h; (c) exposure to liquid Li for 792h.

Fig.6 The appearance of steel surface: (a) exposure to liquid Li for 264h; (b) exposure to liquid Li for 528h; (c) exposure to liquid Li for 792h; (d) exposure to liquid Li for 1320h; (e) XRD surface analysis for 304SS specimen's surface after exposure to liquid Li for 1320h; (f) elements profiles by EDS scanning of 304SS exposed to Li for 1320h at 600 K.

Fig.7 The metallographic structure of corrode sample after exposure to static Li at 600 K for 792h.

Fig.8 Elements profiles by EDS line scanning of 304SS exposed to Li for 1584h at 600 K.

Fig. 9 Vickers hardness curve on 304SS surface before and after exposure to static Li at 600 K for 0h to 1584h, compared with area ratio of precipitates at the same time.

Fig.10 The different Vickers hardness values with different surface positions.

Fig.1

Fig.2

Fig.3

Fig.4

Fig.5

(a)

(b)

(c)

(d)

Fig.6

Fig.7

Fig.8

Fig.9

Fig.10