TEM STUDY OF HIGHLY IRRADIATED BERYLLIUM ANNEALED AT 500-900 °C

Background

In the design of a thermonuclear fusion reactor, beryllium is a candidate material for constructing the plasma facing material and the neutron multiplier. Hereto, the behaviour of this material under high neutron fluences and high temperatures is being investigated. The production and diffusion of gases like helium and tritium is an important issue as high quantities of these gases are produced as a result of neutron irradiation

Objectives

The second matrix of the Materials Testing Reactor BR2 made of S-200-E grade beryllium, has been irradiated at around 50 °C for 15 years up to a fast neutron fluence (>1MeV) of 4.67×10^{22} n/cm² and was replaced in 1995. In this period about 2.2 % He was produced which is comparable to the amount of He expected in a typical Be fusion reactor at the end of its life. Specimens from this matrix were annealed at temperatures of 500, 750, 825 and 900 °C. In a previous study, the influence of the annealing temperature and time on the He content and the microstructure was investigated with optical and scanning electron microscopy. To complement the observations made, transmission electron microscopy measurements on the same set of specimens were conducted to determine the helium behaviour at nanometer scale.

Principal results

Before annealing, the irradiated material shows a large number of irradiation induced dislocation loops but no helium bubbles. The average loop size is 15 nm and the loop density equals 4×10^{21}/m³. There is a large amount of stress present in these specimens, which shows up as a stray contrast in the TEM images as in figure 1a. This stress is induced by the presence of small helium clusters which are invisible in TEM.

a) b)

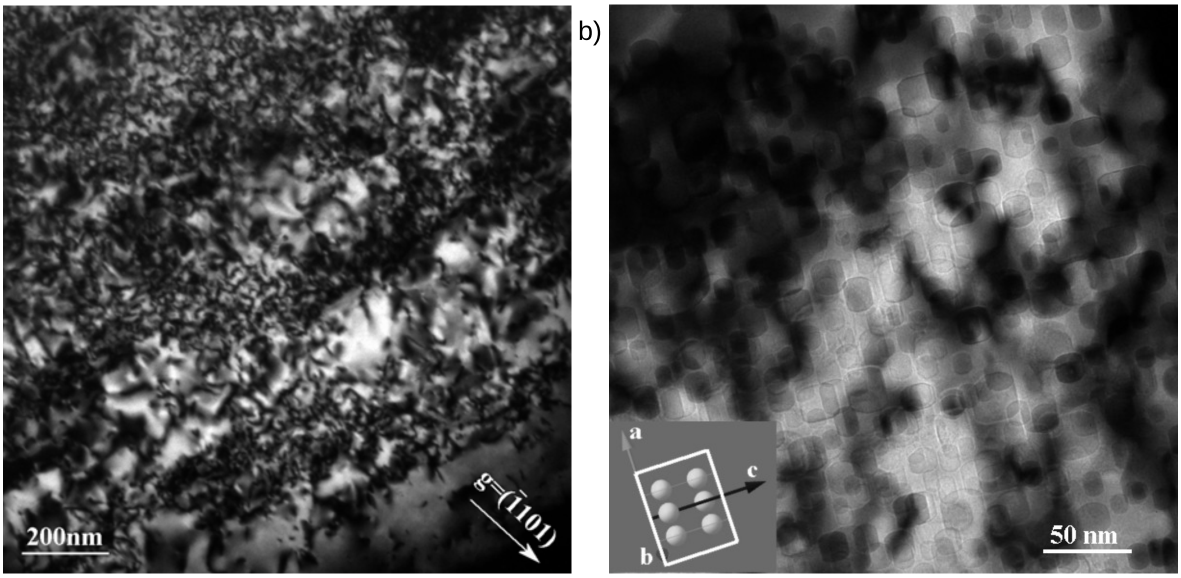


Figure 1: a) Dark field image showing the large amount of stress in the as-irradiated specimen.
b) The helium bubbles formed after annealing at 500°C. The inset shows an enlarged image of the unit cell of the beryllium lattice.

After anneals at temperatures of 500 and 750 °C, a large amount of bubbles with a hexagonal prism shape is observed in the interior of the Be grains (see figure 1b). The bubbles are coherent with the beryllium lattice, meaning that they are oriented parallel to the unit cell of the surrounding beryllium. The average edge lengths are 8.6 nm in the basal plane and 12.3 nm in the c-direction. They are comparable for both annealing temperatures and an increase of the annealing time does not have a significant effect on the bubble size. The area close to the grain boundary, as shown in figure 2a, is found to be defect free, except for some <a> type line dislocations which are also found in the un-irradiated material. The irradiation induced defects are annealed out of the specimen at these temperatures.

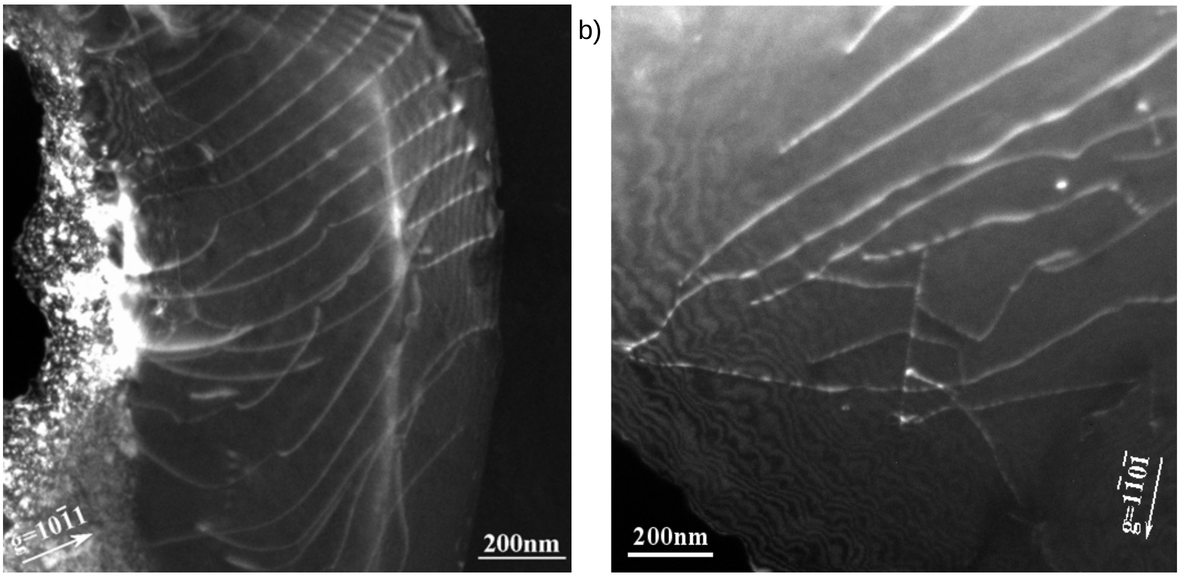
a) 

Figure 2. a) Bubble free zone close to the grain boundary in the specimen annealed at 500°C. b) The defect structure of the specimen annealed at 825°C.

Annealing at 825 and 900 °C results in the removal of virtually all small ^{4}He bubbles observed in the grain interior (see figure 2b). Only the line dislocations, also present in the specimen before irradiation, are observed. The majority of the dislocations are <a>-type, but a small amount of <c>-type dislocations were observed as well.

Regarding the helium mobility, the experiments show that at 500 °C the ^{4}He atoms as well as the radiation induced vacancies are sufficiently mobile to create bubbles. Small faceted bubbles are formed, which are still sessile themselves. The mobility of the gas atoms increases with higher temperature and the saturation of the swelling at 750 °C suggest that all ^{4}He is present in bubbles. The small faceted bubbles are mobile above 825 °C and contribute to the further growing of the large grain boundary bubbles, but this does not induce a further significant swelling of the beryllium.

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Main reference

W. Van Renterghem, A. Leenaers, S. Van den Berghe, J. Nucl. Mater (2007), doi:10.1016/j.jnucmat.2007.07.007