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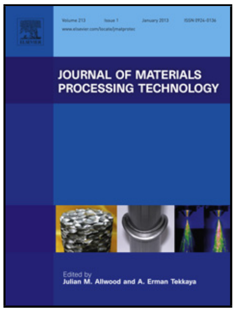

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Nanosized polycrystalline diamond cladding for surface protection of zirconium nuclear fuel tubes

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Highlights

- Composite polycrystalline diamond layer prepared by chemical vapor deposition protect zirconium alloys nuclear fuel cladding against undesirable and dangerous surface reactions.
- Protective layer consilidate zirconium alloys chemical stability and preserve its functionality.
- Good radiation tolerance of the composite polycrystalline diamond layer as well as its protective capabilities against hot steam oxidation were confirmed.

Abstract

A 300 nm thick polycrystalline diamond layer has been used for protection of zirconium alloy nuclear fuel cladding against undesirable oxidation with no loss of chemical stability and preservation of its functionality. Deposition of polycrystalline diamond layer was carried out using microwave plasma enhanced chemical vapor deposition apparatus with linear antenna delivery (which enables deposition of PCD layers over large areas). Polycrystalline diamond coated zirconium alloy fuel tubes were subjected to corrosion tests to replicate nuclear reactor conditions, namely irradiation and hot steam oxidation. Stable radiation tolerance of the polycrystalline diamond layer as well as its protective capabilities against hot steam oxidation of the zirconium alloy were confirmed. Finally, the use of polycrystalline diamond layers as a sensor of specific conditions (temperature/pressure dependent phase transition) in nuclear reactors is suggested.

Keywords: polycrystalline diamond film, nuclear fuel cladding protection, microwave plasma enhanced chemical vapor deposition

1. Introduction

Zirconium alloys (with a common subgroup trademarked Zircaloy2) are a material used in all modern hot steam water cooled commercial nuclear reactors. Such a material must comply with stringent material requirements; Zinkle S J and Was G S (2013) described the recent material challenges of nuclear-reactor materials. Zircaloy2 is a material with very useful properties for nuclear facilities applications: it has a low absorption cross-section of thermal electrons, high ductility, hardness and corrosion resistance. However, it also has significant weakness, as it reacts with water steam, as recently reviewed by Burns et al (2013). During this (oxidative) reaction hydrogen gas is released; the oxidation rate of such a reaction was studied by Causey et al (2006). The released hydrogen then partly diffuses into the alloy forming zirconium hydrides, which are less dense and are mechanically weaker than the original Zircaloy2 material. Their formation results in blistering and finally cracking of the cladding, mechanisms of which were studied by Puls et al (1990). Moreover, a large production of hydrogen gas can result in a hydrogen-air chemical explosions (as seen in the recent Fukushima