ÉCOLE DOCTORALE
Particules, hadrons, énergie et noyau : instrumentation, imagerie, cosmos et simulation (PHENIICS)

PhD thesis of Gabriel BOUHALI

prepared at IJCLab, under the supervision of Stéphanie JUBLOT-LECLERC and Aurélie GENTILS

Defence scheduled on Thursday 21st December 2023, 2 pm
IJCLab, Building 100, salle des conseils

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Title : Effects of ion irradiation and gas injection on the microstructural evolution of AlN

Keywords : Ion implantation, Helium bubbles, AlN, Defects, Strain, Temperature

Abstract : Insulating and optical materials will be used in future fusion reactors to operate in a variety of applications among which diagnostic systems. AlN, specifically, has been proposed as an insulating coating in some fusion reactor concepts. Applications in fusion reactors require that the material resists the effects of 14 MeV neutrons with the production of both He and H at high rates. The materials facing plasma will also be exposed to intense fluxes of low energy He and H. It is consequently imperative to clarify the mechanisms responsible for the degradation of the microstructural properties of AlN under irradiation and gas injection. During the course of this PhD, single He, Al and Au ion implantations were performed on monocrystalline AlN layers. The microstructural evolution was characterized with a combination of TEM and XRD experiments and simulations. The effects of He injection were studied as a function of implantation temperature. Evidence for strong dynamic annealing with efficient point defect recombination is shown already at RT. The point defect recombination is found to be enhanced with increasing implantation temperature where He concentration is low, indicating increased mobility of interstitial-type defects. A reversed effect is observed for sufficient He concentration: thermally activated mechanisms related to the nucleation and growth of He-V complexes overcome the point defect recombination and promote the elastic strain and damage build-up. A threshold He concentration for the formation of bubbles is estimated for each temperature of implantation and found to decrease with the temperature. Al and Au ion implantations performed at RT at similar dpa rates result in similar trends for the damage and strain build-up. Up to around 1 dpa, the near surface and maximum strain values are found to be similar for similar dpa values, and they are moreover found to be similar for both ions. At higher dpa, the near surface strain saturates at a similar strain value and for similar dpa in both kinds of implantation. A saturation of the maximum strain is also observed at higher dose, in concomitance with the saturation of the size of basal stacking faults, but the maximum strain is observed to be significantly higher in the case of Al implantation. As the disorder does not seem to be more important in the case of Au implantation, with in particular similar size of BSFs at similar dpa values in both cases, this difference between Al and Au implantations is ascribed to a more efficient point defect recombination in the dense cascades of Au implantations. Successive He implantations and irradiations were also performed to study the stability of He bubbles under irradiation as well as a potential effect of pre-existing damage on the formation of bubbles. An unexpected and unreported phenomenon of surface amorphization was detected. Finally, thermal annealing experiments were performed on He as well as Al implanted samples up to 1100°C to observe in particular the effects of annealing on the growth of cavities as well as extract activation energies from the observed strain relaxation to correlate them to basic point defect mechanisms.