Taming Nanostructures: From Sponge to Dot Pattern on Ge Controlled by Heavy-Ion-Deposited Energy

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The self-organization of highly ordered patterns on surfaces, induced by ion beam irradiation, has attracted attention as potential nanostructured templates for magnetic and plasmonic applications. The origin of the high spatial order and its dependence on ion irradiation parameters are still under discussion. In agreement with former studies we found that ion irradiation of Ge with heavy ions (here: Bi) leads to a strong change in surface morphology in terms of roughness and formation of amorphous porous layers (sponge) with a thickness of about six times the projected ion range[1].

Here, we present our finding that the surface morphology on Ge, caused by irradiation with focused Bi monomer and cluster ions, can be controlled by the deposited energy density as well as the substrate temperature. While, at room temperature, the irradiation with Bi cluster ions can lead to highly ordered dot pattern[2] having high aspect ratios (figure 1), irradiation with Bi monomers results in the well-known porous surface patterns ranging from holes via columns to sponge (figure 2). At elevated substrate temperatures, highly ordered dot structures can be achieved by monomer irradiation too (figure 3). The pair correlation of these SEM images reveals that dot formation occurs in a temperature range which depends on the energy density deposited by a single ion. At very high temperatures, surface diffusion leads to smoothing.

A cellular defect structure model[3] based on ion beam induced strong defect creation and high vacancy mobility in Ge explains the formation of holes, columns and sponge-like structures at low atomic energies in the cascade, i.e. Bi monomer irradiation at room temperature. This defect formation is incapacitated by thermal spikes, which form at elevated temperatures or by cluster ion impacts. The dependence of the observed dot formation on the deposited energy density and the substrate temperature under normal ion beam irradiation cannot be explained by any model published up to now[4,5,6].

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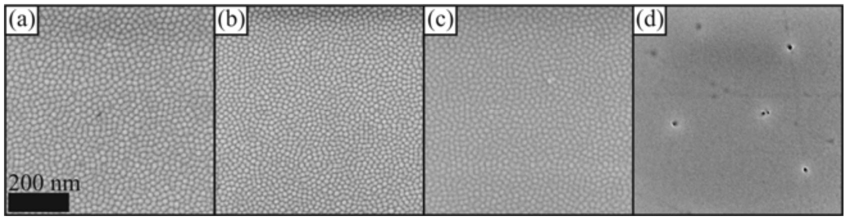

Figure 1: SEM images of surface nanopatterns on Ge by Bi cluster irradiation at room temperature. The fluence was $1x10^{17}$ ions/cm². A terminal voltage of 30 kV corresponds to projectile energies of: (a) 20 keV/at for Bi_3^{2+}, (b) 15 keV/at Bi_2^{+}, (c) 10 keV/at for Bi_3^{+} and (d) 7.5 keV/at for Bi_4^{+}.

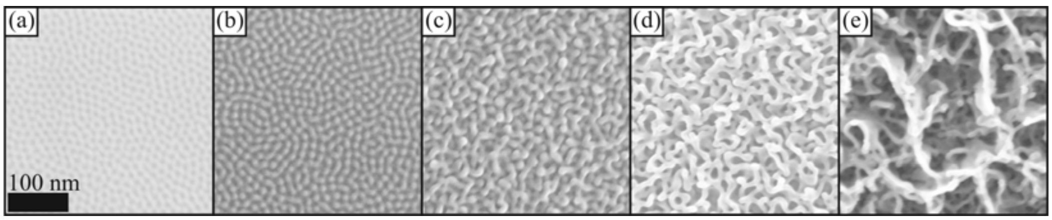

Figure 2: SEM images of surface nanopatterns on Ge by Bi monomer irradiation at room temperature. The fluence was $1x10^{17}$ ions/cm². Holes, columns or sponge like pattern form depending on the ion energy, which is increasing from left to right: (a) 5 keV, (b) 10 keV, (c) 20 keV, (d) 30 keV, (e) 60 keV.

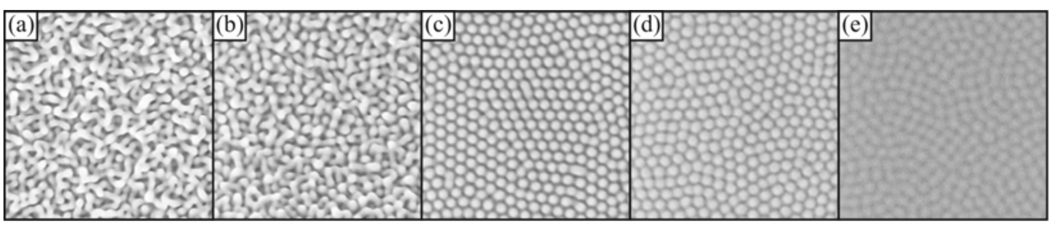

Figure 3: SEM images of surface nanopattern evolution on Ge by 20 keV Bi monomer irradiation elevated temperature. The fluence was $1x10^{17}$ ions/cm². The sponge like structure changes to a hexagonally ordered dot patterns and vanishes with increasing temperature: (a) 100 °C, (b) 200 °C, (c) 300 °C, (d) 350 °C, (e) 400 °C.