Membrane folding by He^+ ion implantation for three-dimensional device fabrication

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We demonstrate that silicon nitride membranes can be folded via He^+ ion implantation. The folds have a 1.25μm radius (Fig. 1) for 150nm-thick silicon nitride. There is no visible sputter damage from the implantation. By varying the ion energy, we can control whether the membrane folds up or down (Fig. 2). This agrees with our theory that implanted ions occupy space in the membrane, causing stress. The stress is compressive and proportional to the concentration of implanted ions at any point in the membrane. Varying the energy of the incident ions changes the depth to which the ions are implanted and, therefore, the location of stress in the membrane. Ions implanted between 14.5-22.5 keV stop near the bottom of the membrane and fold it upwards. Ions implanted between 6.5-10.5 keV stop near the top of the membrane and fold it downwards. This technique can be used to fold patterned membranes into dense 3D arrangements for device fabrication.

These results improve upon our previous work which was limited by (i) a 30μm fold radius[1] and (ii) sputter damage that weakened the membrane when implanting with Ga^+ ions.[2]

Previous studies of ion-implantation-induced stress concluded that the stress is proportional to the energy of the ions lost to nuclear collisions.[3] These studies found that the stress reaches a maximum when the ion dose is approximately 10^{16} ions/cm^2 and the studies did not investigate higher doses. In our experiments, we found that doses of $>10^{17}$ ions/cm^2 were required to fold the membrane more than 10 degrees. At doses of 10^{16} ions/cm^2 the stress due to ion concentration in the lattice is less than the stress from nuclear collisions. Therefore, our theory does not contradict previous theories but applies to a different ion dose range.

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1 W. J. Arora, A. J. Nichol, H. I. Smith, and G. Barbastathis, Appl. Phys. Lett. **88**, 053108 (2006).

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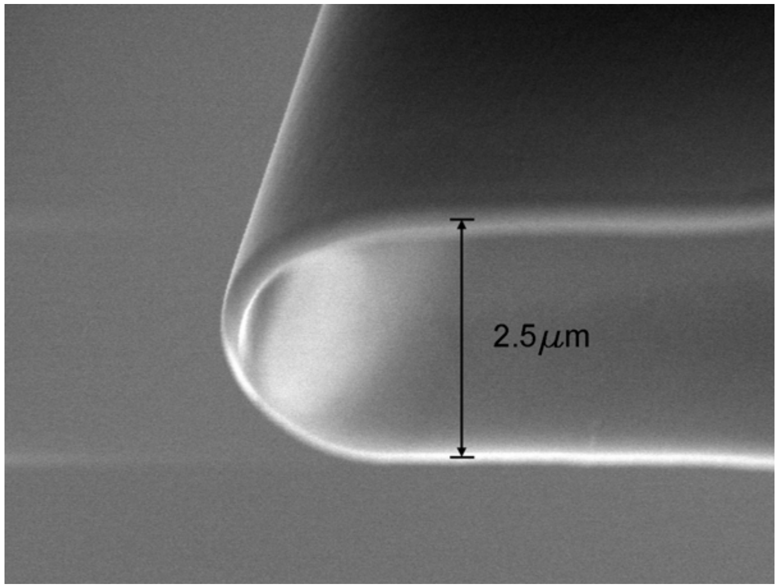

Fig 1: Magnified view of a 150nm thick silicon nitride cantilever folded to almost 180^o. The fold radius is approximately 1.25μm.

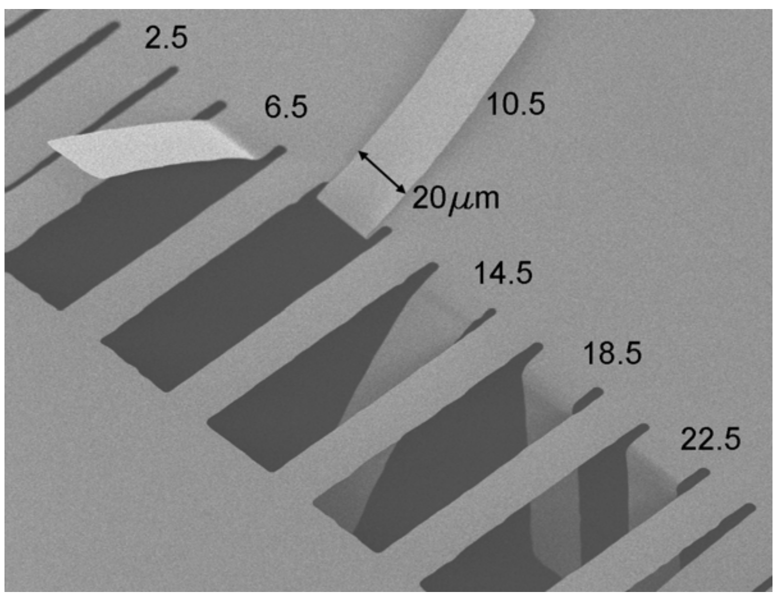

Fig 2: A 150nm thick silicon nitride membrane patterned into 20x100μm cantilevers. Implanted areas were 4x20μm and received an ion dose of $2.5x10^{17}$ ions/cm^2. This picture was taken from the backside of the membrane for clarity. The implantations were conducted from the topside of the membrane. The number next to each cantilever is the He^+ ion energy in keV.