

used for some gas separation processes. Holes in the size range 0.7 nm to 1.2 nm may be used for some desalination processes.

[0012] In view of the foregoing, scalable processes for perforating graphene and other two-dimensional materials in order to produce holes with a high hole density, narrow size distribution and a small hole size would be of considerable interest in the art. In particular, scalable processes to produce holes having a size, hole density, and size distribution suited for various filtration applications would be of considerable interest in the art. The present disclosure satisfies the foregoing needs and provides related advantages as well.

SUMMARY

[0013] According to one aspect, there is provided a process comprising: exposing a multilayered material to ions provided by an ion source, the multilayered material comprising a first layer comprising a two-dimensional first material and a second layer of a second material in contact with the first layer, the ions being provided with an ion energy ranging from 1.0 keV to 10 keV, and a flux from 0.1 nA/mm² to 100 nA/mm²; and producing a plurality of holes in the two-dimensional first material by interacting a plurality of ions provided by the ion source, neutralized ions or a combination thereof with the two-dimensional first material and with the second material.

[0013a] In various embodiments, processes for perforating a two-dimensional material are described herein. In one aspect, exposure of a composite of a layer including the two-dimensional material and a layer of another material to a source of ions produces a plurality of holes in the two-dimensional material even when the energy and/or flux of the ions is relatively low. In an embodiment, the layer of the other material is not a layer or sheet of a two-dimensional material.

[0014] In some embodiments, the processes for perforation can include (1) exposing a two-dimensional material in contact with at least one layer of a material other than the two-dimensional material to an ion source and (2) interacting a plurality of ions from the ion source with the two-dimensional material and with the at least one layer. In an embodiment, the at least one layer is in continuous contact with the two-dimensional material while the two-dimensional material is being exposed to the ion source. In an embodiment, the ions introduce a plurality of defects in the two-dimensional material and an interaction of the ions with the at least one layer promotes expansion of

the defects into a plurality of holes defined in the two-dimensional material. In embodiments, the ion source provides an ion energy ranging from 0.75 keV to 10 keV, from 1 keV to 10 keV, from 1 keV to 5 keV, from 2 keV to 10 keV, or from 5 keV to 10 keV. In embodiments, the ion source provides an ion dose ranging from 1×10^{10} ions/cm² to 1×10^{17} ions/cm², from 1×10^{11} ions/cm² to 1×10^{15} ions/cm², or from 1×10^{13} ions/cm² to 1×10^{19} ions/cm².

[0015] In an embodiment, the process comprises the steps of exposing a composite