Atomic and Close-to-atomic Scale Manufacturing of Large-scale Solid-state Nanopore Array

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Nanopore is a 1~100 nm dimension hole that brings extraordinary properties to various applications. Although biological nanopores have been successfully commercialized in DNA sequencing, solid-state nanopores are proved in laboratory capable of enabling more robust, sensitive, and reliable devices required by the industry, thus are considered as the next generation nanopore with various advantages. Although many efforts have been devoted to the fabrication of solid-state nanopores in the recent two decades, most laboratory attempts to date still create single solid-state nanopores at a time, with high cost and low efficiency, resulting in little uptake by industry. Thus, even though some research demonstrated the superior performance of solid-state nanopore array over single nanopore sensor, only limited progress in the lab has been reported occasionally, such as using 4, 9 or 36 solid-state nanopores. To date, successful manufacturing of millions of solid-state nanopores in a single chip has not been reported. In this article, a hybrid manufacturing method is proposed and validated in fabricating a large quantity of solid-state nanopores simultaneously in a single chip. Experiments have evidenced nanopore chip size over 10 mm^2 containing over 2.6 billion solid-state nanopores, with pore size down to 20-70 nm when maintaining a good uniformity, and minimum nanopore film thickness reaching 4 nm. Simulation reveled a controllable atomic migration mechanism for regulating the 3D geometry of nanopore channel, and proved an unprecedented inhomogeneous pore channel variation phenomenon, as well as observed the closure of nanopores. This provides a new possibility for forming irregular nanopore geometries to enable disruptive working mechanisms, such as single molecules trapping in high-throughput detection. The whole manufacturing cycle performed less than 3 hours, even shorter using more efficient machines, and the average cost of a single chip is less than 50 euro, much favorable for mass production and industrial applications. This method was also applied to fabricate large-scale micropore array for large molecules/cells capturing and separation, such as circulating tumor cells, which indicated excellent performance.

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