A NANOFENCE ARRAY FOR DNA ELECTROPHORESIS
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ABSTRACT
This paper reports a new post array geometry for separating long DNA by electrophoresis. The device provides a separation resolution comparable to that achieved in dense arrays of nanoposts without requiring any direct-write nanopatterning such as electron-beam lithography.

KEYWORDS: DNA Electrophoresis, Post Array, Projection Lithography

INTRODUCTION
Microfabricated devices provide a powerful approach for separating long DNA because, in contrast to gels, the pore size of the separation medium is decoupled from its mechanical stability [1]. Arrays of micron or sub-micron diameter posts have received significant attention [1], and the best separation resolutions to date have taken place in dense arrays of nanoposts [2,3]. Such devices require sophisticated clean room processing and are expensive to fabricate, especially at the prototyping stage. Devices made by conventional photolithography [4,5] or the self-assembly of magnetic beads [6,7] are much easier to produce, but do not have the resolving power of nanopatterned systems. Our new system combines the best aspects of both types of devices, providing high resolution with a simple fabrication procedure.

THEORY
Our “nanofence” device [10], shown in Fig. 1, provides the resolving power of the dense nanopatterned post arrays while only requiring optical lithography to create the pattern. The principle behind this device arises from our recent fundamental insights into the separation mechanisms in a post array [8,9]. Explicitly, we found that the variance in holdup times and the variance in distance between collisions contribute equally to the band broadening in these devices, provided that the DNA only hooks around one post during a given collision. The nanofence is designed such that the DNA is forced to collide at the fixed interval between posts in order to pass to the next nanofence. The distance between collisions is no longer a random variable, which reduces the band broadening. Moreover, since the distance between fences is approximately equal to the average distance between collisions in a hexagonal post array [8], the distance between peaks should be the same. As a result, the nanofence provides sharper separations than hexagonal arrays of microposts [4,5] and a resolution comparable to dense arrays of nanoposts [2,3].

EXPERIMENTAL
We fabricated the device using the protocol illustrated in Fig. 2, using a combination of projection lithography and deep reactive ion etching. The finished device features 600 nm, oxidized posts with a gap size of 600 nm between posts. A single fence consists of two rows of these posts offset by 600 nm, and the fences are spaced by 20 µm. The entire device consists of 500 nanofences in the separation channel and a shifted-T injection.

Figure 1: Scanning electron microscope (SEM) images of the nanofence array. (a) Tilted view of the nanofence array with 20 µm distance between fences. (b) Magnified image of the nanofence array showing the smooth nanopost side walls. The nanoposts are 600 nm in diameter and 2 µm high.
RESULTS AND DISCUSSION

As seen in Fig. 3, we have studied the separation of $\lambda$-DNA and its digest at 10 V/cm. The separation resolutions, shown in Table 1, are comparable to that realized in sparse micropost arrays [3] and magnetic beads [4] with an order-of-magnitude decrease in separation time. We also achieve a resolution of 1.3 after 112.2 s for the separation of $\lambda$-DNA and T4-DNA at an electric field of 20 V/cm, which is comparable to the separation in dense arrays of nanoposts in the same period of time.

Table 1. Separation Resolutions of $\lambda$ and the XhoI $\lambda$-digest at 10 V/cm

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>33.5-15 kbp</th>
<th>48.5-15 kbp</th>
</tr>
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<tr>
<td>179.4</td>
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<td>1.60</td>
</tr>
<tr>
<td>201.8</td>
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<td>1.68</td>
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<td>224.3</td>
<td>0.93</td>
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<td>269.1</td>
<td>1.00</td>
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<tr>
<td>291.5</td>
<td>1.10</td>
<td>1.82</td>
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<tr>
<td>358.7</td>
<td>1.14</td>
<td>1.82</td>
</tr>
<tr>
<td>425.9</td>
<td>1.17</td>
<td>1.94</td>
</tr>
</tbody>
</table>

Figure 2: Schematic illustration of the typical procedure for fabricating a nanofence array in a microfluidic channel. (a) Spin-casting SPR955 photoresist on thermal oxide. (b) Projection lithography. (c) Removal of thermal oxide by reactive ion etching (RIE). (d) Silicon etching by deep reactive ion etching (DRIE). (e) Electrical insulation of the silicon substrate by growing thermal oxide. (f) Anodic bonding between 500 µm thick borofloat glass and oxidized silicon substrate.

Figure 3: Evolution of the bands during DNA electrophoresis. (a) Separation of $\lambda$ and the XhoI $\lambda$-digest at an electric field of 10 V/cm. (b) Separation of $\lambda$ and T4-DNA at an electric field of 20 V/cm.
CONCLUSION

We presented a new design of an oxidized silicon nanofence array for long DNA electrophoresis. Long DNA electrophoresis in the nanofence array offers high separation resolution by reducing the band broadening. The scanning detection method provides a detailed evolution of DNA electrophoresis, and a convenient and accurate method to evaluate fundamental physical parameters such as the migration velocity, mobility, and dispersion coefficient.

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REFERENCES


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