Reducing Facet Nucleation During Algorithmic Self-Assembly

Supporting Information

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July 3, 2007

Methods

All reactions were performed in Tris Acetate EDTA buffer (TAE) supplemented with 12.5 μM $MgCl_2$. Gel electrophoresis of individual tiles was performed in 10% polyacrylamide with 0.6% by volume 10% v/v ammonium persulfate solution (APS), crosslinked with 0.04% tetramethylethylenediamine (TEMED). Gels were run in buffer kept at 4 $^\circ$C by a temperature bath. We stained the gels with Sybr Gold (Invitrogen Corporation) for 35 minutes, then imaged them with a Bio-Rad Molecular Imager FX with external laser. Atomic force microscopy was performed as described in previous work.[1,2]

References

(1) Rothemund, P. W. K.; Papadakis, N.; Winfree, E. *PLOS Biology* **2004,** *2,* 424–436.
(2) Barish, R. D.; Rothemund, P. W. K.; Winfree, E. *Nano Lett.* **2005,** *5,* 2586–2592.
(3) Schulman, R.; Winfree, E. Synthesis of crystals with a programmable kinetic barrier to nucleation, *submitted.*
(4) Bloomfield, V. A.; Crothers, D. M.; Tinoco, Jr., I. *Nucleic Acids: Structures, Properties, and Functions;* University Science Books: Sausalito, CA, 2000.

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Figure 1. **Sequences for the uniform proofreading tiles.** The sequences for the four (or six) strands of each sequence are shown, along with a simple diagram that shows the complementary regions and arrangement of the sequences. In these diagrams, a "$>$c" denotes c as the 5' end of a sequence and "$<$g" denotes g as the 3' end of a sequence.

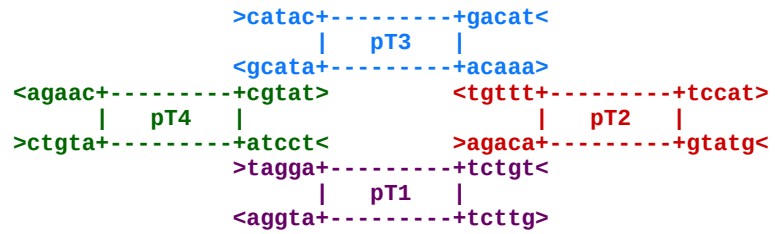

Figure 2. **Block structure for the uniform proofreading tiles.** The logical arrangment of tiles and their respective sticky ends.

Figure 3. **Sequences for the snaked proofreading tiles.**

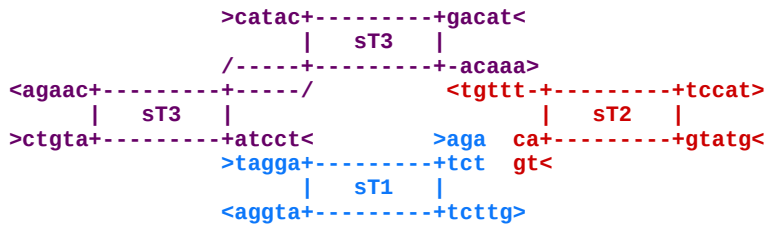

Figure 4. **Block structure for the snaked proofreading tiles.** The logical arrangment of tiles and their respective sticky ends. Note the blunt end (coaxial) stacking of helices between tiles sT1 and sT2.

```
                                          5  <gaagcagg-acaagcga\/ctcagtgt-ccgattgg>  3
                                       6  >catac-cttcgtcc tgttcgct/\gagtcaca ggctaacc-tccaa<  4
                                                        | |       Z78H     | |
     2  >cattctgg-acgccata\/tctatcgt-ccgatgac-gacag-ccgtgcca ggtagcgg\/tacactcc tgcttctg-ttcct>  4
1  <agaac-gtaagacc tgcggtat/\agatagca ggctactg-ctgtc-ggcacggt-ccatcgcc/\atgtgagg-acgaagac\
                | |       Z78H     | |                                                  tcgca<  3
1  >aggtt-ctaccgca ggcaaatg\/tcagctcc tgcctagc-acctt<  5
     2  <gatggcgt-ccgtttac/\agtcgagg-acggatcg<  6

  1  aggttctaccgcaccagaatgcaaga
  2  cattctggacgccataagatagcacctcgactcatttgcctgcggtag
  3  acgctcagaagcaggagtgtaggcgatggtgttcgctctcagtgtccgattgg
  4  aacctccaatcggtgcttctgttcct
  5  ttccacgatccgtggctactgctgtcggcacggtccatcgcctacactccacactgagagcgaacaggacgaag
  6  cataccttcgtccaccgtgccgacagcagtagcctgctatcttatggcgtggcaaatgagtcgaggacggatcg
```

```
     2   >cagagtgg-acgaaagc\/agtgccgt-ccgatgtc<  3
  1  <aagga-gtctcacc tgctttcg/\tcacggca ggctacag-aagag>  4
                | |       Z1       | |
  1  >cttgt-caaacgca ggaacctg\/tatgaacc tgctcaac-tcgta<  4
     2   <gtttgcgt-ccttggac/\atacttgg-acgagttg>  3

  1  cttgtcaaacgcaccactctgaggaa
  2  cagagtggacgaaagctcacggcaccaagtatcaggttcctgcgtttg
  3  ctgtagcctgccgtgagctttcgtggaacctgatacttggacgagttg
  4  atgctcaactcgtggctacagaagag
```

```
       2   >gatgatgt-ccttgtaa\/tgaagcgg-acaacgag<  3
  1  >ttagc-ctactaca ggaacatt/\acttcgcc tgttgctc-gctaa>  4
                | |       Z2       | |
  1  >aagtc-gaacgacc tgattgcg\/taatctca ggcattcg-cacta<  4
       2   <cttgctgg-actaacgc/\attagagt-ccgtaagc>  3


  1  aagtcgaacgaccacatcatccgatt
  2  gatgatgtccttgtaaacttcgccactctaatcgcaatcaggtcgttc
  3  gagcaacaggcgaagtttacaaggtgattgcgattagagtccgtaagc
  4  atcacgcttacggtgttgctcgctaa
```

Figure 5. **Sequences for zig-zag ribbons, part one.**

```
      2   <gtcggtca-ggctcgtc\/acgacacc-tgagacgg>  3
  1  >tggaa-cagccagt ccgagcag/\tgctgtgg actctgcc-gaaca<  4
                | |       Z3       | |
  1  <ttctc-gaggatgg acgcttag\/tctgtagt ccgcattg-aatcg   4
         /ctcctacc-tgcgaatc/\agacatca-ggcgtaac\
  2  >acaag                                  cagtg<  3

  1   tggaacagccagtggtaggagctctt
  2   acaagctcctacctgcgaatctctgtagtggtgtcgtctgctcggactggctg
  3   gtgaccaatgcggactacagagattcgcaccgagcagacgacacctgagacgg
  4   acaagccgtctcaccgcattgaatcg
```

```
        2  <ccgttagg-acattgca\/cggcttgt-ccgttcgc>  3
    1  >agcat-ggcaatcc tgtaacgt/\gccgaaca ggcaagcg-ttcag<  4
                | |       Z4       | |
    1  <cgatt-cgccaaca ggttgaat\/ccagatcc tgtagagc-gacat>  4
        2  >gcggttgt-ccaactta/\ggtctagg-acatctcg<  3

  1   agcatggcaatccacaaccgcttagc
  2   gcggttgtccaacttaccagatccacaagccgacgttacaggattgcc
  3   gctctacaggatctggtaagttggtgtaacgtcggcttgtccgttcgc
  4   gacttgcgaacggtgtagagcgacat
```

```
                                          5  <gcaagcgt-ccacttgg\/gcagtagg-acgcctcg>  3
                                  6  >gtgat-cgttcgca ggtgaacc/\cgtcatcc tgcggagc-gcaat<  4
                                            | |       Z56B     | |
    2  >gtttgagg-acgctatg\/ttgtaggt-ccatgagc-acgaa-cgaaagcc tgagctag\/tccagaca ggtcatcg-aaggc>  4
1  <ctgta-caaactcc tgcgatac/\aacatcca ggtactcg-tgctt-gctttcgg-actcgatc/\aggtctgt-ccagtagc-ttccg<  3
             | |       Z56B     | |
1  >cgtta-gctcggca ggtgtctc\/acgaatcc tggttacg-aaggc<  5
    2  <cgagccgt-ccacagag/\tgcttagg-accaatgc-ttccg>  6

  1   cgttagctcggcacctcaaacatgtc
  2   gtttgaggacgctatgaacatccacctaagcagagacacctgccgagc
  3   gccttcgatgacctgtctggagatcgagtggtgaaccgcagtaggacgcctcg
  4   taacgcgaggcgtggtcatcgaaggc
  5   cggaagcattggtggtactcgtgcttgctttcggactcgatctccagacacctactgcggttcacctgcgaacg
  6   gtgatcgttcgcaccgaaagcaagcacgagtacctggatgttcatagcgtggtgtctctgcttaggaccaatgcttccg
```

Figure 6. **Sequences for zig-zag ribbons, part two.** The extra bases on tiles Z3 (5′ ends of strands 2 and 3) and Z78 (5′ end of strand 3) were used due to an unintentional strand mixup. To our surprise, while the melting temperature of the zig-zag structure with these bases was lower than would be predicted by the hybridization energy of DNA, the structure otherwise formed and behaved as designed. Removing these bases is desirable and raises the melting temperature of the ribbons by about 8-10 degrees,[3] to close to what would be preicted by previously measured nearest neighbor energies of DNA hybridization.[4] However, as this error was not noticed until all experiments were complete, and as zig-zag ribbons nonetheless formed satisfactorily, we did not correct it.

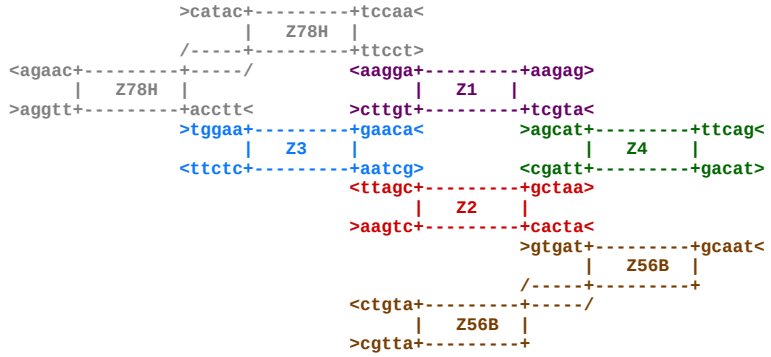

Figure 7. **Block structure for the zig-zag ribbons.** The logical arrangment of tiles and their respective sticky ends.

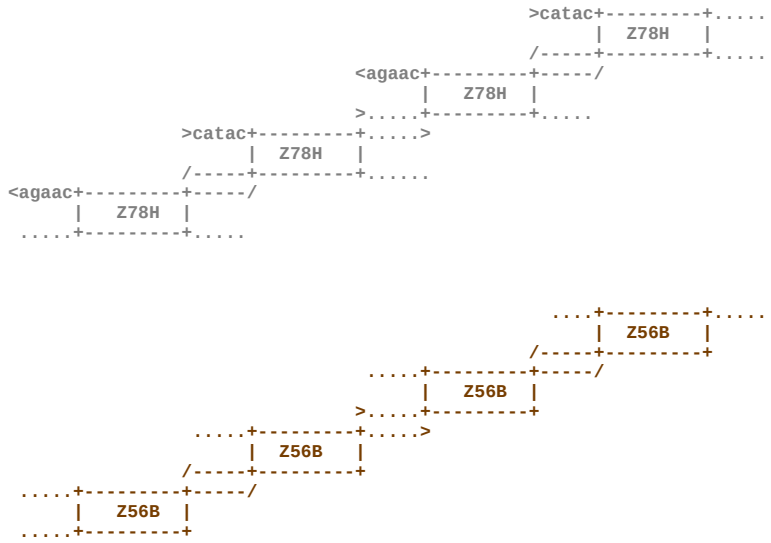

Figure 8. **Hard facet for the zig-zag ribbon ZZhard.** The sequences of the double tiles used to make the zig-zag with a hard facet are exactly those given in Figures 5 and 6.

Figure 9. **Easy facet for the zig-zag ribbon ZZeasy.** The zig-zag ribbon encoding the easy facet consists of the tiles in Figures 5 and 6 except for tile Z78, which was modified as shown.

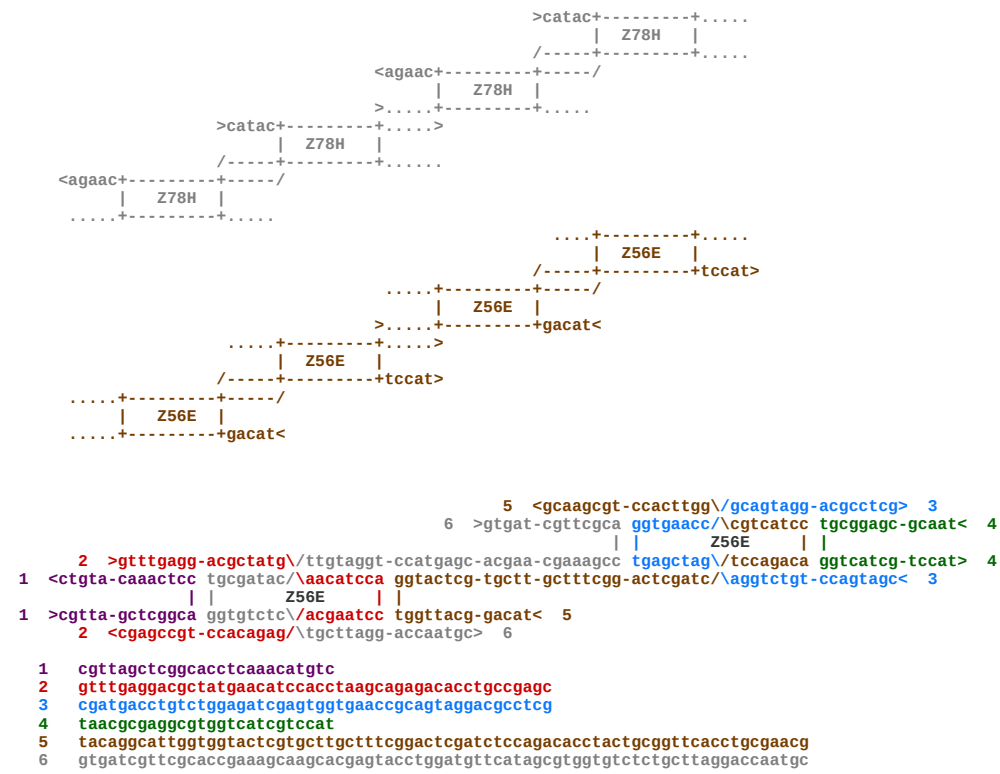

Figure 10. **Double sided zig-zag ribbon ZZhardeasy.** These ribbons are the same as those used for the hard facet (Figures 5, 6 and 8, except for tile Z56 which was modified as shown.

Figure 11. **Double sided zig-zag ribbon ZZeasyhard.** This ribbon consists of the tiles in Figures 5, 6 and 9 except for tile Z56 which was modified as shown.

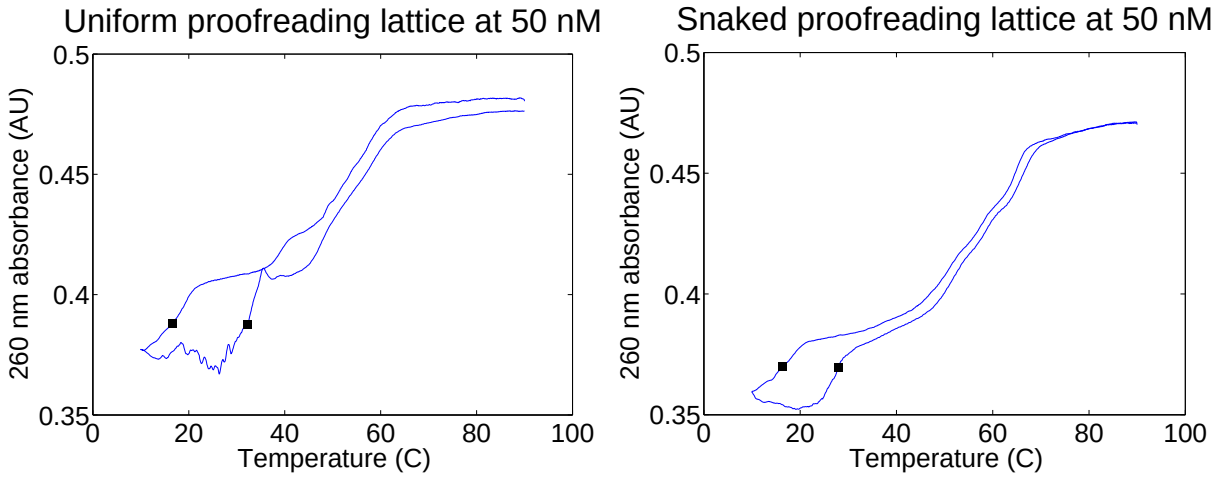

Figure 12. **Anneal and melt curves for the uniform and snaked proofreading lattices.** Melts were performed in an AVIV-14DS Spectrophotometer (AVIV Biomedical, Lakewood, NJ). Each sample was annealed from 90 °C to 10 °C at approximately 0.13 °C / minute. To complete lattice formation before melting, samples were held at the lowest temperature, 10 °C, for two hours, then melted from 10 °C to 90 °C at the same speed as the anneal. The top line of each melt is the absorbance during annealing, the bottom during melting. Based on previous work,[1–3] we conclude that the reversible transition between 45 °C and 70 °C is due to tile formation, while the lower temperature irreversible transition is due to the nucleation and growth of the respective lattice. The noise in the melt of the uniform proofreading lattice is presumed to be due to scattering of light – the lattices grew larger than the 260 nm wavelength used to measure absorbance. To measure the relative stability of the lattices, we defined the formation temperature as the temperature at which lattice formation progressed 50% of the way, and the melting temperature as the temperature at which melting progressed 50% of the way. We assumed the absorbance of formed tiles prior to lattice formation to be the absorbance at 42 °C during the melt, while the minimum absorbance was taken to represent full lattice formation. Formation and melting temperatures are marked with black squares. Both formation temperatures are around 16 °C. While it is hard to compare the melting temperature of the two lattices because of scattering during the uniform proofreading experiment, the melting temperature of the uniform lattice was significantly higher than the melting temperature of the snaked proofreading lattice: 32 °C vs. 28 °C. This may be partially due to kinetic effects. Uniform proofreading lattices were larger than the snaked proofreading lattices, suggesting kinetic differences. Furthermore, the melting of zig-zag ribbons (1-dimensional DNA tile crystals) is known to occur out of equilibrium at the speed at which we performed these melts,[3] suggesting that the same could be the case for these 2-dimensional DNA tile crystals. However, the difference in melting temperatures could also indicate that the snaked proofreading lattice is destabilized, for example because of the asymmetry of the tiles.