Electronic Supplementary Material (ESI) for ChemComm.

Electronic Supplementary Information

Stepping operation of rotary DNA origami device

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Experimental Section

Preparation of rotary nanodevice

All staple strands were purchased from Eurofins Genomics Tokyo (Tokyo, Japan). Single stranded M13mp18 viral DNA was purchased from tilibit nanosystems (Garching, Germany). DNA origami structures were designed using the caDNAno software.[1] Assembly of origami structures was accomplished by mixing 4 nM M13mp18 scaffold DNA with ~20 nM of staple strands in 25 µL of the TAE-Mg buffer containing 40 mM Tris-acetate (pH 8.3), 1 mM EDTA and 12.5 mM $MgCl_2$. The mixture was annealed as follows:

1) Heat at 65 °C for 15 min.
2) Cooling from 65 °C to 45 °C at a rate of −1.0 °C/h.
3) Cool and store at 25 °C.

The assembled structure was purified by PEG-precipitation.[2]

Agarose Gel Electrophoresis

The samples were loaded to electrophoresis on a 1.0% agarose gel containing 5 mM $MgCl_2$ in a 0.5 x TBE (Tris-borate-EDTA) buffer solution (pH 8.0) under 50 V at 4 °C. The gels were then imaged by ChemiDOC™ MP (Bio-Rad Laboratories, Inc., CA, U.S.A.) using SYBR® Gold Nucleic Acid Gel Stain (Thermo Fisher Scientific, MA, U.S.A.) as staining dye

AFM observation

AFM imaging was performed using Nano Live Vision (RIBM, Tsukuba, Japan) or BIXAM (OLYMPUS, Tokyo, Japan). Typically, a drop (2 µL) of the sample (5 nM) was deposited onto a freshly cleaved mica surface. After 1 min incubation, the surface was rinsed with 10 µL of the TAE-Mg buffer, and then scanned in ~ 120 µL of the TAE-Mg buffer. *In situ* operation of the rotary devise was performed as follows:

1) Deposit 2 µL of sample (4 nM) onto a freshly cleaved mica.
2) Rinse the surface with TAE-Mg buffer.
3) AFM imaging in TAE-Mg buffer.
4) Rinse the surface with TAE-Mg buffer.
5) Deposit 2 µL of DNA solution containing a pair of holding strands (500 nM each DNA srand).
6) Incubate 10 min at RT.
7) Rinse the surface with TAE-Mg buffer.
8) AFM imaging in TAE-Mg buffer.
9) Rinse the surface with TAE-Mg buffer.
10) Deposit 2 µL of DNA solution containing a pair of releasing strands (2 µM each DNA strand).
11) Incubate 10 min at RT.
12) Rinse the surface with TAE-Mg buffer.
13) AFM imaging in TAE-Mg buffer.

Holding strands and releasing strands were dissolved in the TAE-Mg buffer prior the experiment. Sequential operation of the rotor was performed by repeating steps 4) - 13) with different sets of holding and releasing strands. The sample surface was scanned in ~ 120 µL of the TAE-Mg buffer with a small cantilever (9 µm long, 2 µm wide and 130 nm thick; BL-AC10DS, Olympus) having a spring constant of ~0.1 N/m and a resonant frequency of ~300–600 kHz in water. Typically, 320 × 240 pixel images were obtained at a scan rate of 0.2 frames per second. AFM images were analysed using the AFM Scanning System Software (Olympus, Tokyo, Japan) and lab-made image selector.

1. S. M. Douglas, A. H. Marblestone, S. Teerapittayanon, A. Vazquez, G. M. Church and W. M. Shih, *Nucleic Acids Res.*, 2009, **37**, 5001-5006.
2. E. Stahl, T. G. Martin, F. Praetorius and H. Dietz, *Angew. Chem. Int. Ed. Engl.*, 2014, **53**, 12735-12740.

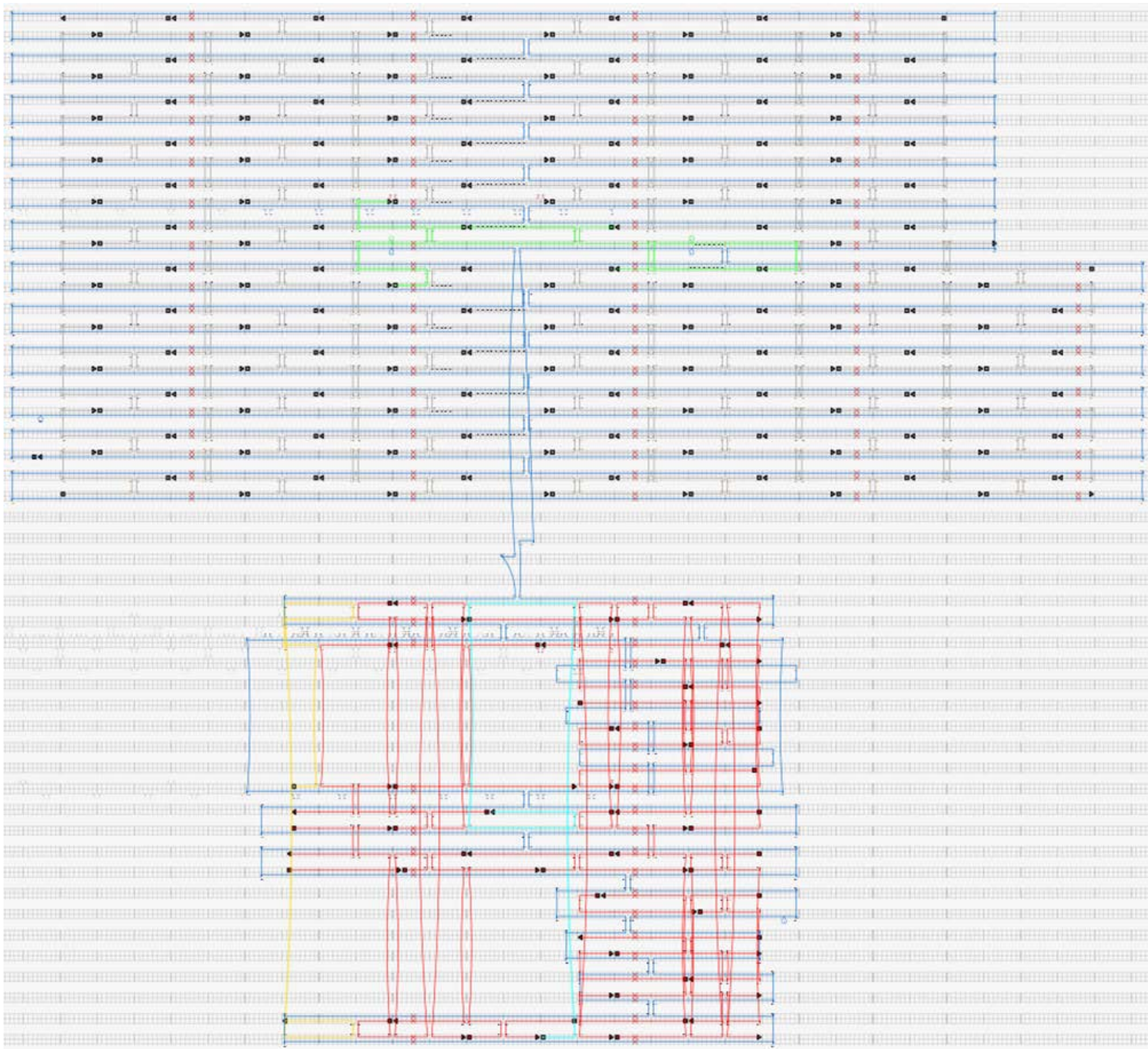


Fig. S1. Design of the rotary DNA origami device.

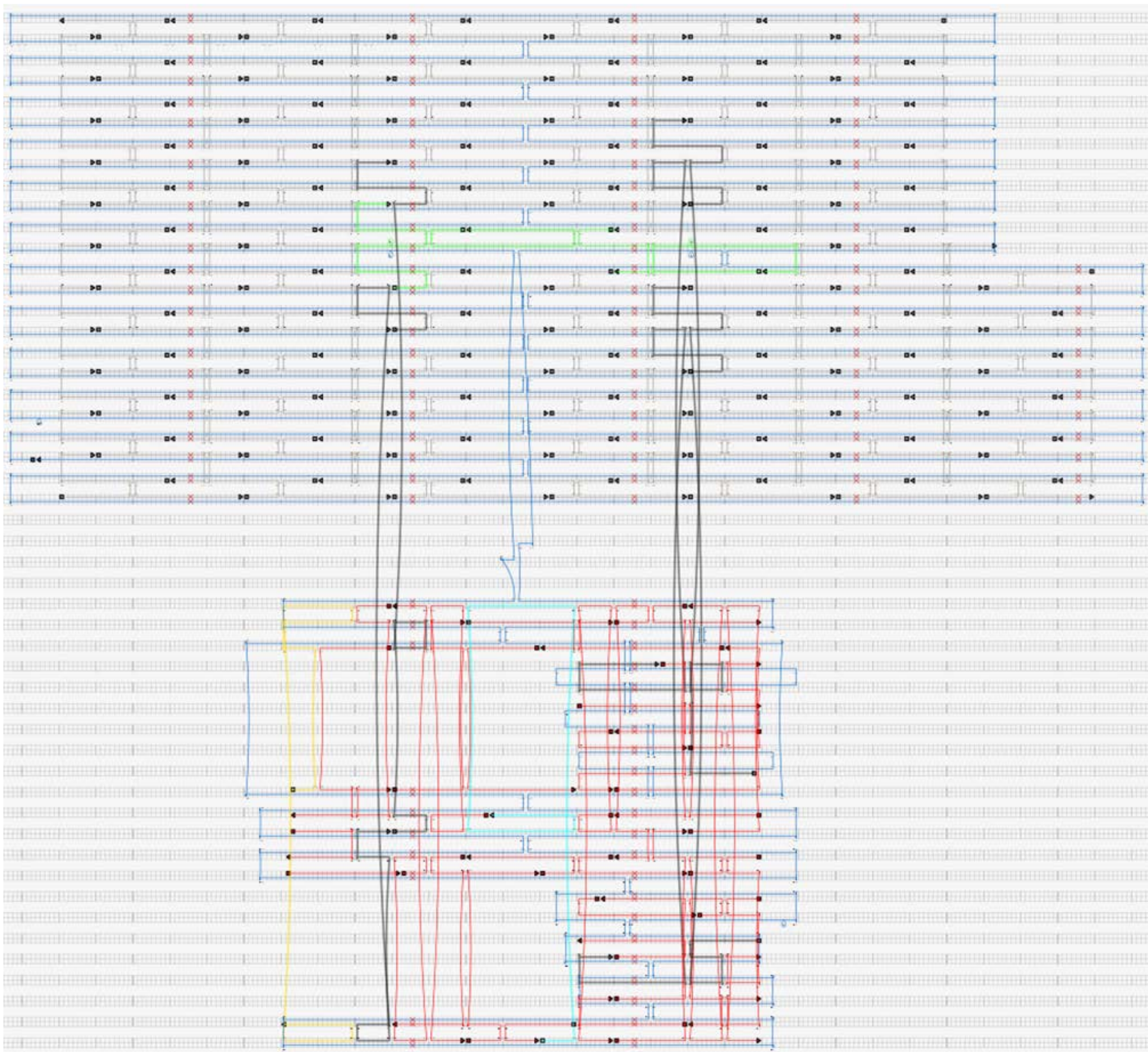


Fig. S2. Design of the rotary DNA origami device having extended staple strands to tether the rotor.

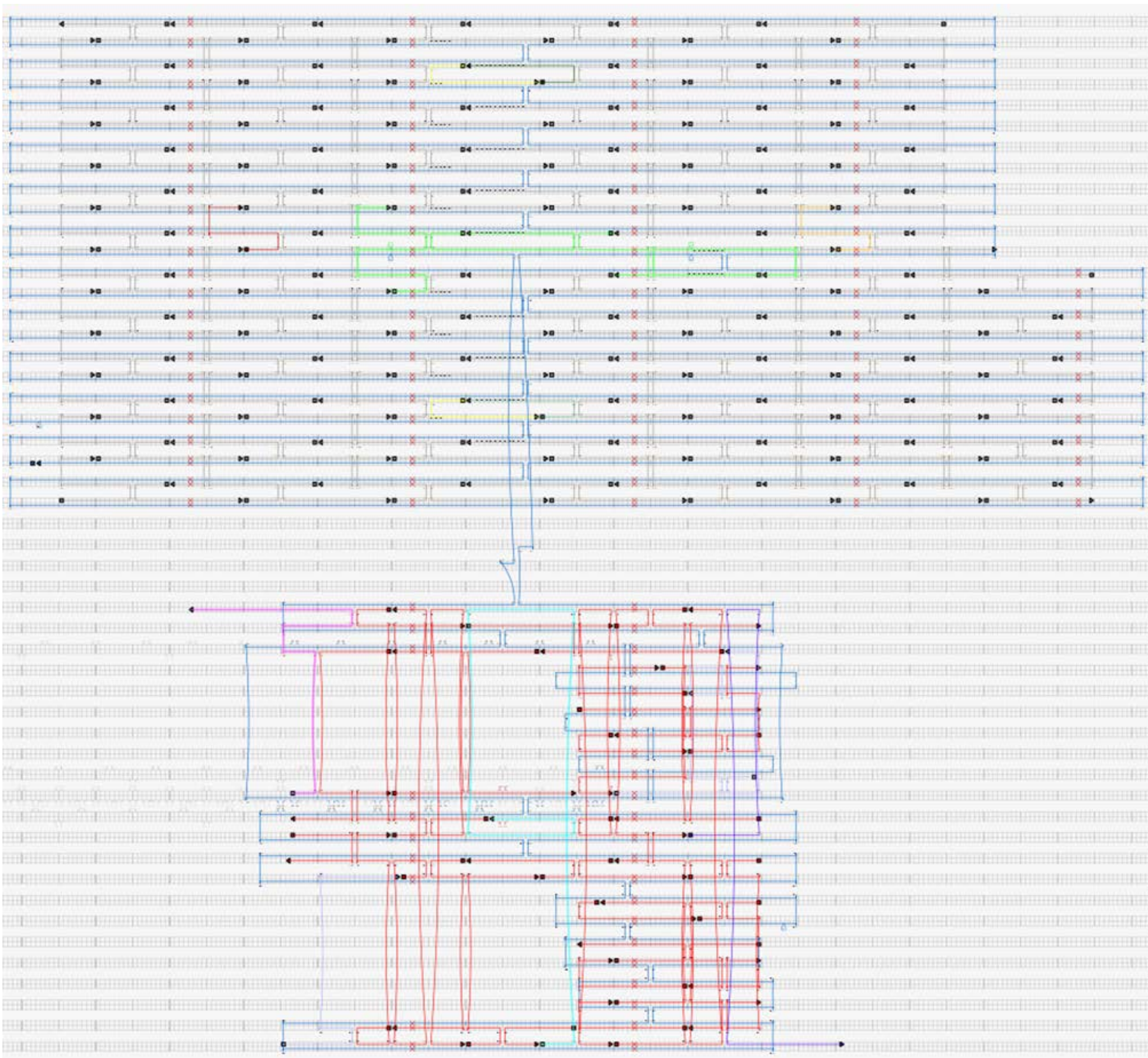


Fig. S3. Design of the rotary DNA origami device having anchor strands.

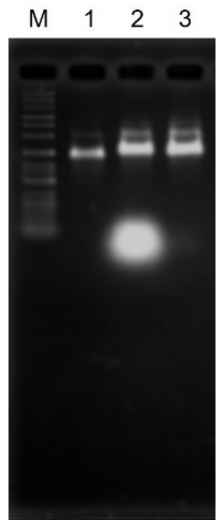


Fig. S4. Agarose gel electrophoresis analysis of rotary origami device. Lane M: 1 kbp ladder; lane 1: M13mp18 scaffold DNA; lane 2: unpurified rotary origami device; lane 3: purified rotary devise.

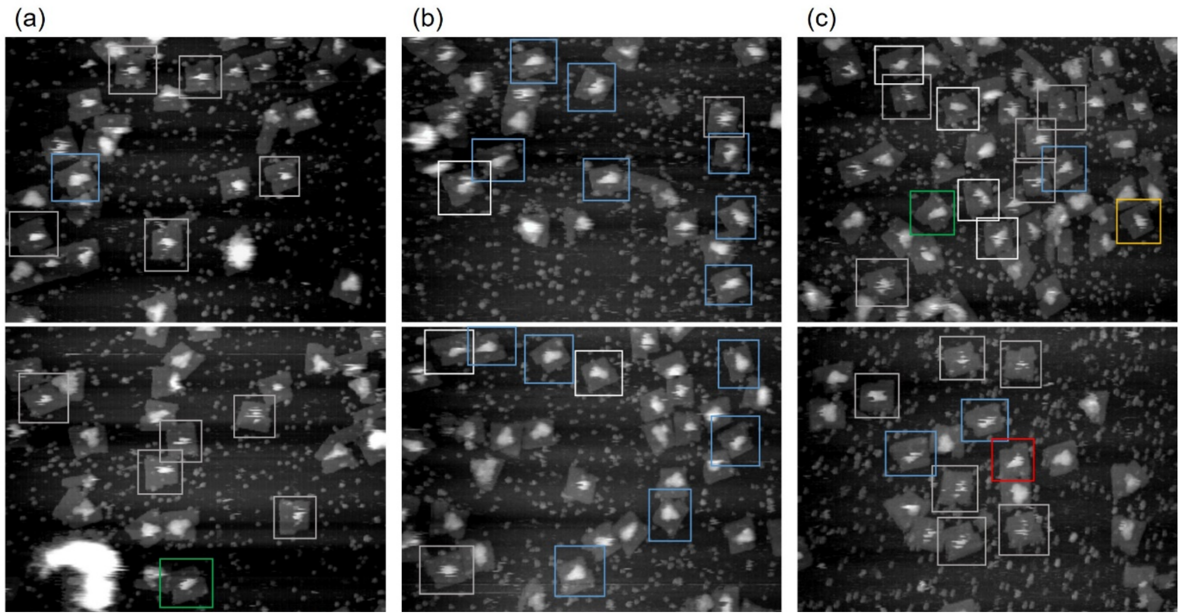


Fig. S5. Representative AFM images of rotary origami at each step of operations on the mica substrate. (a) Unlocked, (b) locked at 0°, (c) released from 0°. Rotors pointing at an angle of 0°, 90°, 180° and -90° are indicated by squares colored with blue, red, green and orange, respectively. Rotors in unlocked state are indicated by grey rectangles. Undistinguished structures are indicated by white rectangles. Image size: 800 nm × 600 nm.

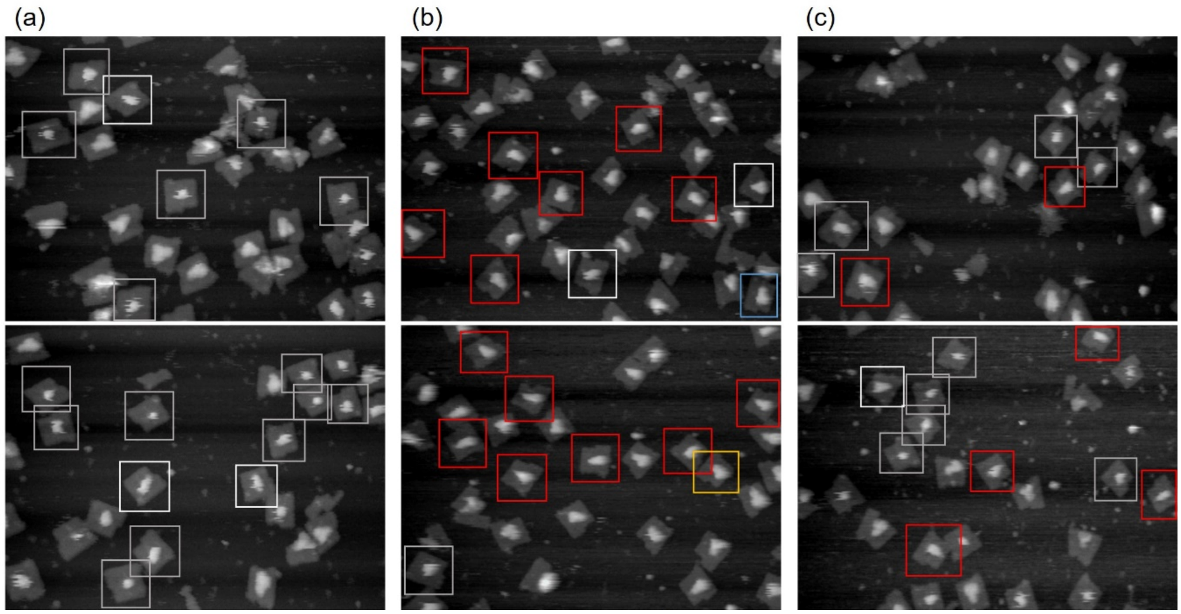


Fig. S6. Representative AFM images of rotary origami at each step of operations on the mica substrate. (a) Unlocked, (b) locked at 90°, (c) released from 90°. Rotors pointing at an angle of 0°, 90°, 180° and -90° are indicated by squares colored with blue, red, green and orange, respectively. Rotors in unlocked state are indicated by grey rectangles. Undistinguished structures are indicated by white rectangles. Image size: 800 nm × 600 nm.

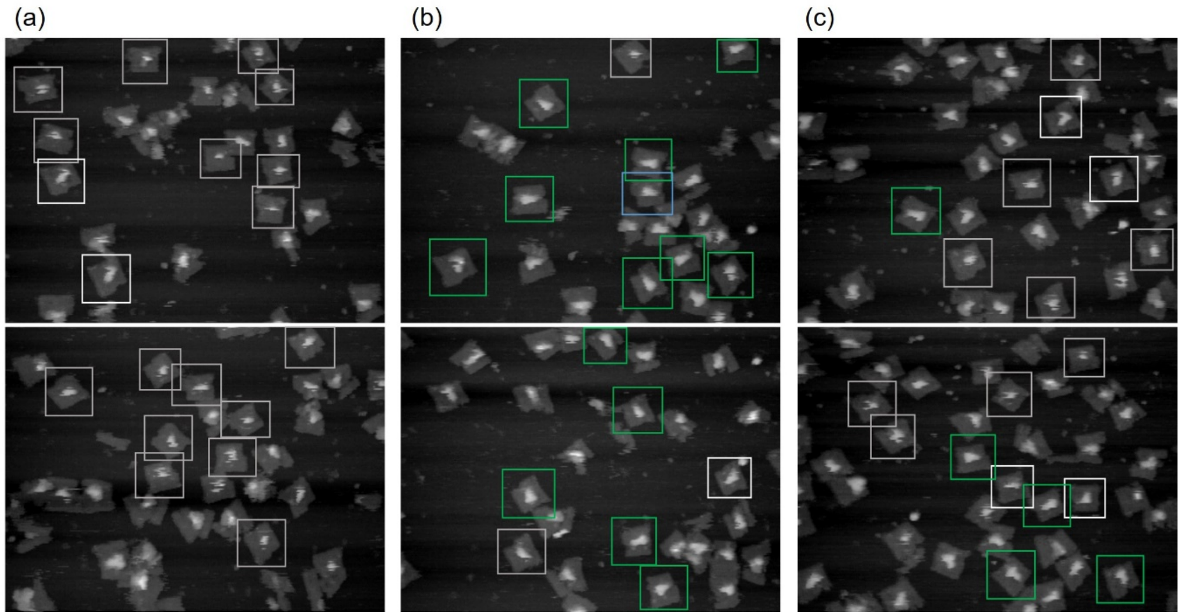


Fig. S7. Representative AFM images of rotary origami at each step of operations on the mica substrate. (a) Unlocked, (b) locked at 180°, (c) released from 180°. Rotors pointing at an angle of 0°, 90°, 180° and -90° are indicated by rectangles colored with blue, red, green and orange, respectively. Rotors in unlocked state are indicated by grey rectangles. Undistinguished structures are indicated by white rectangles. Image size: 800 nm × 600 nm.

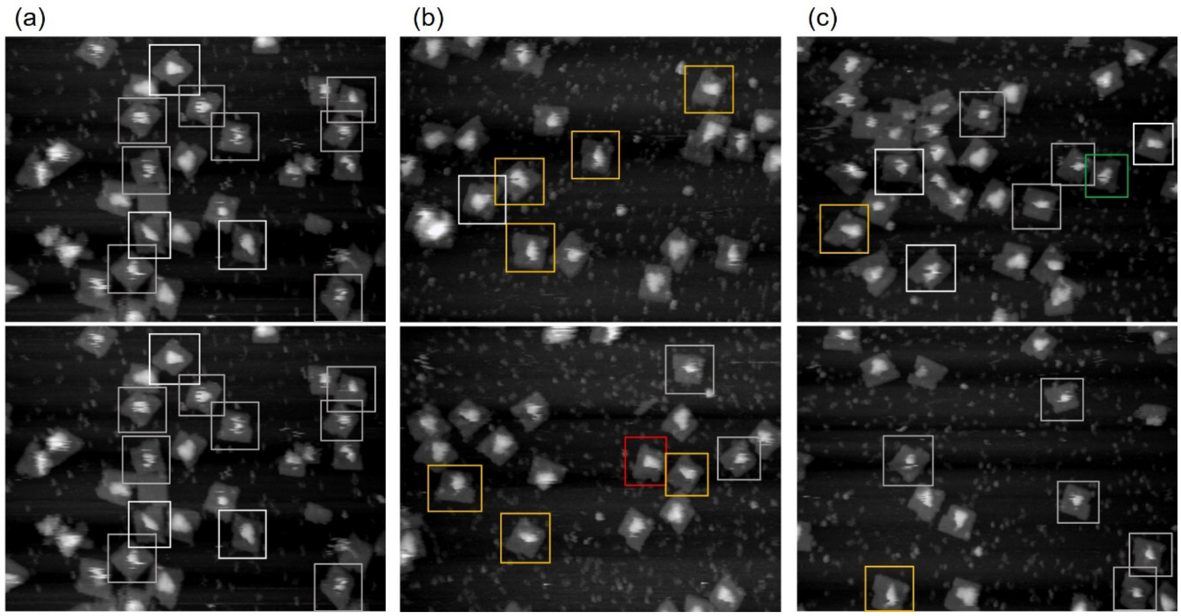
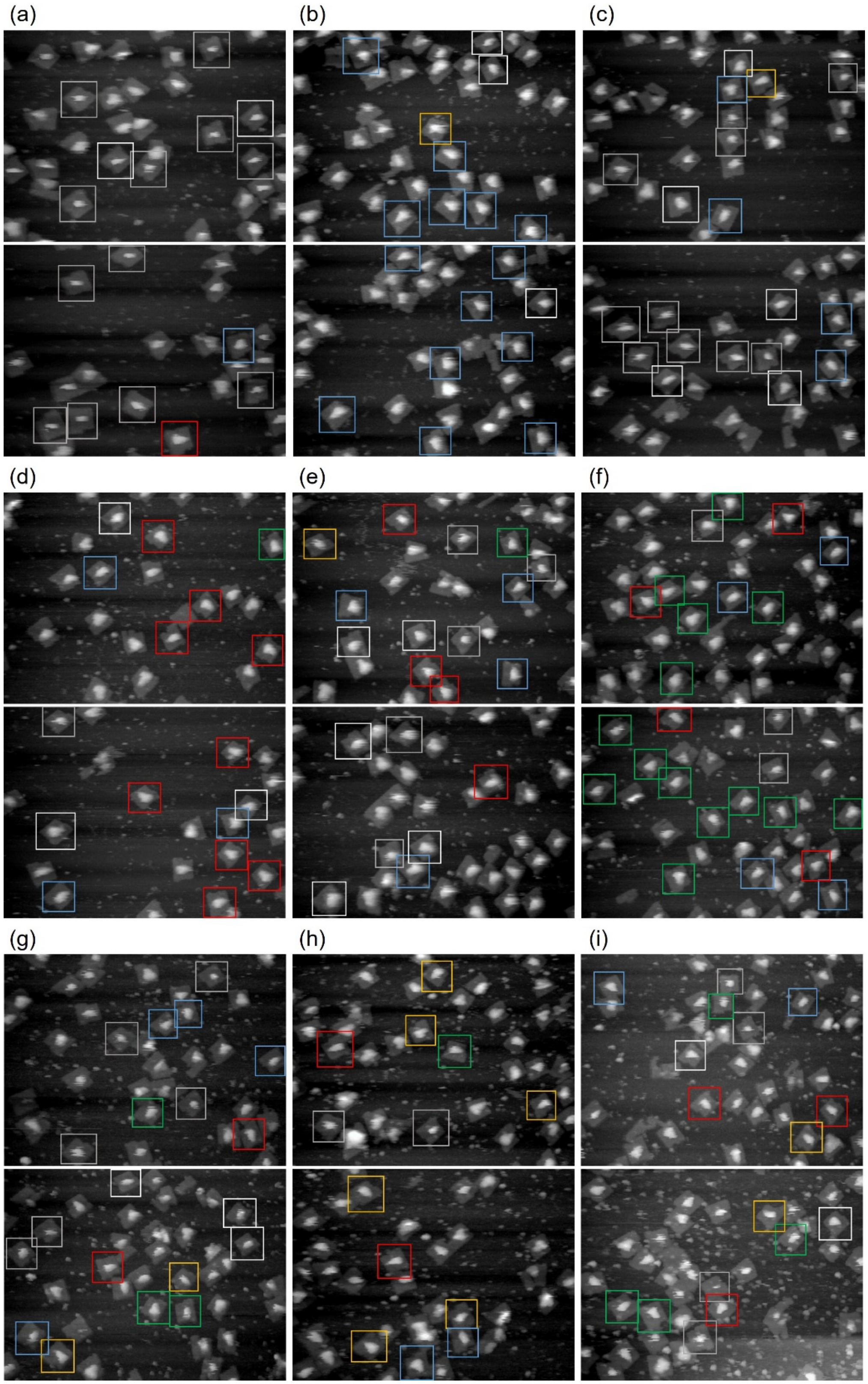


Fig. S8. Representative AFM images of rotary origami at each step of operations on the mica substrate. (a) Unlocked, (b) locked at -90°, (c) released from -90°. Rotors pointing at an angle of 0°, 90°, 180° and -90° are indicated by squares colored with blue, red, green and orange, respectively. Rotors in unlocked state are indicated by grey rectangles. Undistinguished structures are indicated by white rectangles. Image size: 800 nm × 600 nm.



(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)

Fig. S9. Representative AFM images of rotary origami at each step of the sequential operations on the mica substrate. (a) Unlocked, (b) locked at 0°, (c) released from 0°, (d) locked at 90°, (e) released from 90° (f) locked at 180°, (g) released from 180°, (h) locked at -90° and (i) released from 90°. Rotors pointing at an angle of 0°, 90°, 180° and -90° are indicated by squares colored with blue, red, green and orange, respectively. Rotors in unlocked state are indicated by grey rectangles. Undistinguished structures are indicated by white rectangles. Image size: 800 nm × 600 nm.

Table S1. Sequences of staple DNA strands.

Name	Sequence	Length
Base staple1	TAGTAAGTGGCACAGACTAATGCGCCGCTA	30
Base staple2	GAACTCAAGAACCCTTCTGACCTGTAATGCGC	32
Base staple3	CAATAGGACCGCCACCCTCAGAGCGAAACATG	32
Base staple4	TCTGAATGCCGCCACCCTCAGACTTTTCAT	30
Base staple5	CGACCAGTATATTACCGCCAGCCATTGCAACA	32
Base staple6	ATGATACAGATAAGTGCCGTCGAGAGGGTCAGCC	34
Base staple7	AAAATCACATCACCGGAACCAGAGCCACCAAAGG	34
Base staple8	AATTCGCAGTAGATGGGCGCATCGTAACCGCAAA	34
Base staple9	GTGAAATTGGGTACCGAGCTCGAACTGCGCAA	32
Base staple10	GGCCCTGAGGGGAGAGGCGGTTTGTTTCCTGT	32
Base staple11	CAAGCTTGAGCCGGAAGCATAAAGTCGGGAAA	32
Base staple12	TTCTGACTTCTTACCAGTATAAATCGCCAT	30
Base staple13	CAATTACCAAAATTATTTGCACGTCATCATAT	32
Base staple14	CAACCATCTACAGAGGCTTTGAGGATCAGCTC	32
Base staple15	CATAATTACTAGAAAGATAAATAAGGCGTTTAGCTTA	37
Base staple16	CGCTAGGGGGAACAAGAGTCCACTCGGTCCAC	32
Base staple17	GTAGCGCGCCGTAATCAGTAGCGA	24
Base staple18	CGATTGGCCACCAGAGCCGCCGCCGTCAGACT	32
Base staple19	GCCCGGAACAGACAGCCCTCATAGTTAGCAGCAA	34
Base staple20	CATTCCATAGGTGTATCACCGTGCTCAGTA	30
Base staple21	CCAGGCGGGAGTGTACTGGTAAGCGCAGTC	30
Base staple22	TTGCCAGTCAGATATAGAAGGCTTCGTAGG	30
Base staple23	CGGTACGCCAGAATCCCTAAACAGGAGGCCGACGTGGCGA	40
Base staple24	TCGCTATTCGCTGAGAAGAGTCAAGAAATACC	32
Base staple25	CGCTTCTGAAGGGCGATCGGTGCCTCTAGA	30
Base staple26	ATATTAATTGAGTTAAGTACATGGCTTTTG	30
Base staple27	CAGAGATAACTATCGGCCTTGCTGGTAATATC	32
Base staple28	CAATATCTAGCCCTAAAACATCGCCTGGCCAA	32
Base staple29	GCATGTAACCAAGTACCGCACTGCGAACCT	30

Base staple30	TAATAATTTTTCAGCGGAGTGAGAAGCAAGCC	32
Base staple31	AAGAATACTAACATCACTTGCCTGAGTAGAA	31
Base staple32	AATCATTAATCAACAATAGATAAAAACAAC	30
Base staple33	AGTCACGAGCCTAATGAGTGAGCTAACTCATTAT	34
Base staple34	GGATCCCCGTTATCCGCTCACAAAATCGGC	30
Base staple35	TGCGCTCAGGTTCCGAAATCGGCAAAATCTATCT	34
Base staple36	TCCTCATTCCACCACCCTCAGAGCTCGGTCAT	32
Base staple37	TGAGTAACCTCGTATTAAATCCTGCTGAGA	30
Base staple38	TAATTCGCCCCGTCGGATTCTCCCCGGCAC	30
Base staple39	TTTTGATTGAGGAAGGTCCTTATAAATCAA	30
Base staple40	ACCATATCTGAGCAAAAGAAGATGAATTACCT	32
Base staple41	AGAACCACCTTGATATTCACAAAAGTGCCC	30
Base staple42	TGATGGTCTGCCCGCTTTCCAGTGTAAAGC	30
Base staple43	TGCGCGTCCCGAGATAGGGTTGATCCTGTT	30
Base staple44	TAAGACTCCTTACCGAAGCCCTTTAGTCAGAG	32
Base staple45	CCGACTTGCATATAAAAGAAACGTTAGCAA	30
Base staple46	TACATTTAAATGCTGATGTGCATCTGCCAG	30
Base staple47	CTGTTTCCGCGCCCAATGTAACGATCTAAA	30
Base staple48	GCCAGCAGAGGCGGTCAGTATTATGAAATG	30
Base staple49	ATAGCTATCTTATTACGCAGTATGCAAAGACA	32
Base staple50	AATCAAACAGTAGCACCATTACCATTAGCA	30
Base staple51	CCTCAGAAACCCATGTACCGTAAAACAACT	30
Base staple52	GCTGGTTTGCCAGCTGCATTAATGTTCCACAC	32
Base staple53	GAAGATCGACGCCAGCTGGCGAAAGCCAGTGC	32
Base staple54	CAGAACAAATAAAAGGGACATTCATTAAAA	30
Base staple55	AAAAAGGCGTATGGGATTTTGCTACACTGAGT	32
Base staple56	GCAAATTACAAAATAAATGATATAAGTATA	30
Base staple57	AATTAACTTTACAGAGAGAATAACTATTTTGC	32
Base staple58	TAATAAAATACATACATACCGGAACCGCCT	30
Base staple59	CCACGGAATTAAAGGTGAATTATCACCGTCA	31
Base staple60	GACCGTGTAAGCCTGTTTAGTATCTTAGGCAGAGG	35

Base staple61	AAGGATTACAGTGCCTTGAGTAACCAAATAAA	32
Base staple62	ATACCGAACCTCAAATATCAAATACATTTG	30
Base staple63	AGCCCCCTAACGTCACCAATGAAACCATCGA	31
Base staple64	TTCGACAAATTATCATTTTGCGGACAGGTTTA	32
Base staple65	TTATCAAAGAATAACCTTGCTTCTACCAAGTT	32
Base staple66	ACAAGCAAATAATATCCCATCCTAAGGTAAAG	32
Base staple67	AACGCTAAAACGCGAGGCGTTTTACATCGAGA	32
Base staple68	GGTAATTGTGTTTAACGTCAAAAAATCTTACC	32
Base staple69	CGATTTTTAGCGCTAATATCAGAGAAATAGCA	32
Base staple70	ACGTATAACGAGTAAAAGAGTCTGTCCATCAC	32
Base staple71	GGTCGCTGAAGACAGCATCGGAATCAAAAA	30
Base staple72	ACAAAATCAAATTGCGTAGATTTTACAAAGAA	32
Base staple73	TTCAACAGTTTTCACGTTGAAAATATATTC	30
Base staple74	CGGATTCGTGAATATACAGTAACAAAAGTT	30
Base staple75	CCACAAGATTTATCCCAATCCAAGCCTAAT	30
Base staple76	CCCGACTACAATTTTATCCTGATGAAAATA	30
Base staple77	TCCAATTTGTAAACGTTAATATTTTGTTAA	30
Base staple78	AAAATATGATTGTTTGGACATTAATTGCGT	30
Base staple79	TAATTCTGTCCAGACGACGACAATGTCCTGAA	32
Base staple80	AAACATCAGAATAATGGAAGGGTTCATCAA	30
Base staple81	AAAGTATTAGTTAATGCCCCCTGCAGGTCAGA	32
Base staple82	CCTGTCGTGCCCCAGCAGGCGAAAAGTGTTGT	32
Base staple83	TCCAGTTTCGCTGGCAAGTGTAGCTGACGAGC	32
Base staple84	TAGCAGCATTTTCATCGGCATTTCGCCACC	30
Base staple85	ATTATTCATAAGTTTATTTTGTCAGGCATGAT	32
Base staple86	TATAATCCTCTTTAGGAGCACTAAACAGTT	30
Base staple87	AACGGGGTGGATTAGCGGGGTTTTACTCAGGA	32
Base staple88	ACCACCAGAGAAGTATTAGACTTTAGCATCAC	32
Base staple89	ATTTAACTAAAGTACCGACAAAATTTACGA	30
Base staple90	ATTTTTTAGATTGACCGTAATGGGGGCCTCAG	32
Base staple91	TTCAACCGATTGAGGGTCATATGGTTTACCAGACGCAATA	40

Base staple92	CAGGGCGCAACCGTTGTAGCAATACTTCTTTGAT	34
Base staple93	AGCAGCGAAGGCTTGCAGGGAGTTATTGCGAA	32
Base staple94	CTGGGGTCGTTGTAAAACGACGGGGGGATG	30
Base staple95	TCGCTATTCACTCCAGCCAGCTTTGTGGGAAC	32
Base staple96	TATACAAACTAAATTTAATGGTTTTAGTGAAT	32
Base staple97	AACATACGCATGCCTGCAGGTCGAGGGCCTCT	32
Base staple98	GCAAATTGTACTATGGTTGCTTGGTCACGC	30
Base staple99	CAGAGGTGCAAATGAAAAATCTAAACAAACAA	32
Base staple100	AACGTGGAGGGAAGAAAGCGAAAGAATCAG	30
Base staple101	GATTAAGAAATTAATTTTCCCTTACAATAA	30
Base staple102	AATTTTCTTCCAAAAGGAGCCTTTAATGACAA	32
Base staple103	TTCGTCACACCGCCACCCTCAGAACTCAAGAG	32
Base staple104	TGGCAAAGCCATTTGGGAATTAGAGCCAGC	30
Base staple105	TGCTGCAGACGACGACAGTATCATAGGTCA	30
Base staple106	AGTAACAAGTCTGGCCTTCCTGTATCACCCTC	32
Base staple107	ATTCTAAGCGAGCGTCTTTCCAGAATAAGAAA	32
Base staple108	CTTGCTGAACGAACCACCAGCAGACAGTCACA	32
Base staple109	AATAAAGGCGCAGAGGCGAATTTCAATATA	30
Base staple110	ATAACGGAAGATAGCCGAACAAAGGACGGGAG	32
Base staple111	GATTATTTGCTCATGGAAATACC	23
Base staple112	ACTATATGTAACAATTTCATTTGATGAAAC	30
Base staple113	GCAGCCTGAACACCCTGAACAATTAAGAAA	30
Base staple114	CAACGCGCGAGAGTTGCAGCAAGATTAAAG	30
Base staple115	GAGGCCACCGTGCTTTCCTCGTTAGGAGCGGG	32
Base staple116	AGTAAGCATACCCAAAAGAACTCAATCAAT	30
Base staple117	AGAAAATAGGGAAGGTAAATATTGACGGAA	30
Base staple118	GGTTTAGTCAGTACAAACTACAACAGTAAATG	32
Base staple119	CGGTTTAGTCTTTCCAGACGTTGCCTGTAG	30
Base staple120	GGAAAAACACATTGGCAGATTCACAGATAAAA	32
Base staple121	AGCGGGAGTGAGAAGTGTTTTTATAATCAGT	31
Base staple122	ACTTTTTCAAATATATTTTAGTTAGACTACCT	32

Base staple123	ACTTCTAGAAAACAAAACCAGGGTTTTCCC	30
Base staple124	TTTTTAATTCCGGCTTAGGTTGGGGCGAGAAA	32
Base staple125	AGGATTTAAGGAGCGGAATTATAAAACAGA	30
Base staple126	GAAAGGAAATGGCTATTAGTCTTAAAGCGT	30
Base staple127	TTTGAGGGAGGCGATTAAGTTGGGTAACGTTAAT	34
Base staple128	TGTGAGTATCATAGGTCTGAGAATTTCATC	30
Base staple129	GTATAAACAAGAGGCTGAGACTCCCGCCAC	30
Base staple130	GTTTTGTCTCAGCTTGCTTTCGAGGTGAACGCGC	34
Base staple131	CTGTTGGGGTGCCGGAAACCAGGCTGTGAGCG	32
Base staple132	AGGCCGGATATTAGCGTTTGCCATACCGCCAC	32
Base staple133	GAAAGGAACTCCAACGTCAAAGGGCACCGCCT	32
Base staple134	TAGATTAGATCAGATGATGGCAATTAGAACCT	32
Base staple135	CCCTCAGATTACCGTTCCAGTAAGCGTCACCCAA	34
Base staple136	CAAGAAAAGCCGTTTTTATTTTCATATCCGGT	32
Base staple137	GGTATTAAGAAACCAATCAATAATCAGTAATA	32
Base staple138	ACGTCAGACCTGATTGCTTTGAATGTAAATCG	32
Base staple139	ACCCAGCTTGCGGGAGGTTTTGAACAAGAACG	32
Base staple140	GCAACGGCGCCCACGCATAACCGATCTCCAAA	32
Base staple141	GAACTGATGGTCAGTTGGCAAATCACAACTAA	32
Base staple142	AAACGGCGACCAATAGGAACGCCACGAGGGTA	32
Base staple143	TCCTGATTAGCCGTCAATAGATAACCCTCAAT	32
Base staple144	AAGAATAGAACCACCACACCCGCCGCGCTAATAT	34
Base staple145	ACGTAGAAGAGCAAGAAACAATGAGATAAC	30
Base staple146	AGAGAATAAACGCCAACATGTAATATATGCGT	32
Base staple147	TTTTAACCGGAAACAGTACATAAAATTCATTT	32
Base staple148	CCTCAGAGAAAGCCAGAATGGAAATAAGTTTT	32
Base staple149	TATTTAAACGCAAGACAAAGAACTTATATA	30
Base staple for anchor1	TGCGCTCAGGTTCCGAAATCGGCAAAATCTAT	32
base staple for anchor2	CCCTCAGATTACCGTTCCAGTAAGCGTCACCC	32

Rotor staple1	TCATTTTTTTTAAGAACTGAGCGAACCAGAC	31
Rotor staple2	CTGGAGCAAGAGCATACATATAACAGTTGAT	31
Rotor staple3	TGCTCATTAACTTTAAATAACGCCAAAAGGA	31
Rotor staple4	TGAGACTAAATCGGTTGTACCATCCAATAAAAAGCAATA	39
Rotor staple5	AGTACCTTAACTCCAAAGCGTCCATCCCCCTC	32
Rotor staple6	TATGCGATGCGGATGGCTTAACGTAACAAAGC	32
Rotor staple7	GAGAAAGGGTGTAGGTTTTTAAATGCAATGCC	32
Rotor staple8	AAAAAGCGTTTTAATCATTGAAATACTGCG	30
Rotor staple9	GCTGAAAAGGTAACCCTCATATAAAAGATTCATATTTT	38
Rotor staple10	ACCTAAAAATCTTTGATGAACGGTCGGAACGA	32
Rotor staple11	TTTACCCTGACTATTAAATCAAAAGTTCAGAA	32
Rotor staple12	TCACCATCAATATGAGACCCTGTGCAAGGAT	31
Rotor staple13	CCTTCATCAAGAGTGCCCTGACGAGAAAC	29
Rotor staple14	AACGAGAAAACATTATTACAGGTACGAACTA	31
Rotor staple15	TCCCAATTGCTGAATAGAATCGATAGAAGTTT	32
Rotor staple16	AAAATAGCGCAGATACTCATTGTGAATTACCT	32
Rotor staple17	TGAGTAATCCGGAGACATTTCAACAATACTTT	32
Rotor staple18	GTATCATCGCCTGATATACTTAGCGTACAGACCAGGCG	38
Rotor staple19	ATTACGAGTTTACCAGTAAGGCTTAATCTTGA	32
Rotor staple20	ACCACATTCAACTAATGAGAGGCT	24
Rotor staple21	GGCGCAGACGGTCAAGTACAACGCGATTATA	31
Rotor staple22	AAATATCGATTAAGAGTTTAAACAATCAGGTC	32
Rotor staple23	GCAAGGCAGAAACAAATCATAAGGGAACCTAGATTTAGTT	40
Rotor staple24	ACGGAACTGACCATATAGTCAGAAGCAAAATCTACGTT	38
Rotor staple25	AGATACACGTTCTAGCTGATAAATTAATGCCGCTATTTT	39
Rotor staple26	AAAAATTTTTAGGGCATCAATTCAGTAGCATTAACAAAAA	40
Rotor staple27	TGCCAGAGGGGGTAACCTTTTGAGTAGCTCA	31
Rotor staple28	TCATCAGATAAATATTTCGAGCTTCAAGCTCAT	33
Rotor staple29	ATTTCCAGTGAAACGACGAGGCACCA	26
Rotor staple30	AAGCCTCAACAAGATAATGCTTAAGAGG	28

Rotor staple31	GAATCGTCTTGAGATTTAGGAATAGAAAGAT	31
Rotor staple32	CAACTTTGAAAGACGGATATTACTACGAATAAAAACC	37
Rotor staple33	CGGAAGCATAATTGCTTAGTAAAACTGAGAGT	32
Rotor staple34	CATTTGGGATAACCTGTTTAGCTAAAAGGGT	31
Rotor staple35	CAAGAACGGACAGACCCCCAGGAGATTT	28
Rotor staple36	AGTAAATTGGGCTTGAGATGGTTTA	25
Rotor staple37	ACATGTTTTAAATATGGTCATTGCTGTTTAGA	32
Rotor staple38	CATTATTATTCAACTTTCGCAAATGGTCATGACCATT	37
Rotor staple39	CCAAGCGCAAGAATTAGCAAAATTTCATACAG	32
Rotor staple40	TCTGGAAGTTTCATTCAAGGATCTACAAAGGC	32
Rotor staple41	TATACGTTGGGAAGAAAAGCGGATTGCATC	30
Rotor staple42	CCATGTAATTGTGTATACACTAAAACACTCCGAAAGAGGCAAAAGAACTATCATAACCCTCGGCATAGTAAGAGCAAC	78
Rotor staple for anchor 1	ACTATCATAACCCTCGGCATAGTATGGGCTTGAGATGGTTTA	42
Rotor staple for anchor 2	AGATACACGTTCTAGCTGATAAACAATATGAGACCCTGTGCAAGGAT	47
Rotor staple for anchor 3	TCACCATTTAATGCCGCTATTTT	23
Connector staple1	CTCAACAGAACAGGAAGATTGTATTGATAATCACCCCAAATAGGGCTTAATTGAGAAGCCAACG	64
Connector staple2	CGTTGGTTTAAATTTTTGTTAAACTAAAGACATGAGGGATAGTTGCGCCGACAATTGTAT	60
Connector staple3	TTGATACCAAGTTTCCATTAAACGGGTCTAGCATGTCAATCTAATGCAGAATTTCTTAAACAGC	64
Connector staple4	ATGTTCAGCATATGTACCCCGGTAAGCAAA	30
Connector staple rotor side	TTTGCAAAGAACGGTAATCGTTACGTAATGCCCATTACCCAAATCAGAGCTTAATTCTGCGAACGAGGAACTGAC	75

Table S2. Sequences of extended staple strands to tether the rotor.

Name	Sequence	Length
Extended staple1	CAAGAACGGACAGACCCCCAGGAGATTTCGGTTTAGTCTTTCCAGACGTTGCCTGTAG	58
Extended staple2	TGCTGCAGACGACGACAGTATCATAGGTCAATTACGAGTTTACCAGTAAGGCTTAATCTTGA	62
Extended staple3	TCACCATCAATATGAGACCCTGTGCAAGGATATTCTAAGCGAGCGTCTTTCCAGAATAAGAAA	63
Extended staple4	CAAGAAAAGCCGTTTTTATTTTCATATCCGGTAAAAATTTTTAGGGCATCAATTCAGTAGCATTAACAAAAA	72
Extended staple5	TTTACCCTGACTATTAAATCAAAAGTTCAGAATTTTTAATTCCGGCTTAGGTTGGGGCGAGAAA	64
Extended staple6	ACCATATCTGAGCAAAAGAAGATGAATTACCTAACGAGAAAACATTATTACAGGTACGAACTA	63

Table S3. Sequences of anchor strands

Name	Sequence	Length
Anchor X staple	CCATGTAATTGTGTATACACTAAAACACTCCGAAAGAGGCAAAAGATTTTTTTTTTTTTTTTTTTTGTGTGTGTGTGTGTGTGTG	85
Anchor Y staple	ACATGTTTTAAATATGGTCATTGCTGTTTAGACTGTTTTTTTTTTTTTTTTCTCTCTCTCTCTCTCTC	69
Anchor A staple	AAGCATATAAGCTGCTCTGTTTTTGCAACGGCGCCCACGCATAACCGATCTCCAAA	56
Anchor B staple	GTCGACTCACGATCGCAAGTTTTTAATAATAAAATACATACATACCGGAACCGCCT	56
Anchor C staple	CAGATCCGTGAATAAGACGTTTTTATTTAACTAAAGTACCGACAAAATTTACGA	54
Anchor D staple	CAATCGAAGCACCAGTTGGTTTTTCTAAAATATGATTGTTTGGACATTAATTGCGT	56

Table S4. Sequences of holding strands.

Name	Sequence	Length
0_x-a-e	CACACACACACACACACACCAGAGCAGCTTATATGCTTGGACATT	45
0_y-c-f	GAGAGAGAGAGAGAGAGAGCGTCTTATTCACGGATCTGGTCCTCA	45
90_x-b-g	CACACACACACACACACACCTTGCGATCGTGAGTCGACGTCAGTA	45
90_y-d-h	GAGAGAGAGAGAGAGAGAGCCAACTGGTGCTTCGATTGCTCATAC	45
180_x-c-i	CACACACACACACACACACCGTCTTATTCACGGATCTGCTTGGGA	45
180_y-a-j	GAGAGAGAGAGAGAGAGAGCAGAGCAGCTTATATGCTTCACCTGT	45
-90_x-d-k	CACACACACACACACACACCCAACTGGTGCTTCGATTGTGGTTTG	45
-90_y-b-l	GAGAGAGAGAGAGAGAGAGCTTGCGATCGTGAGTCGACATCTGCT	45

Table S5. Sequences of releasing strands

Name	Sequence	Length
0_E-A-X	AATGTCCAAGCATATAAGCTGCTCTGGTGTGTGTGTGTGTGTGTG	45
0_F-C-Y	TGAGGACCAGATCCGTGAATAAGACGCTCTCTCTCTCTCTCTCTC	45
90_G-B-X	TACTGACGTCGACTCACGATCGCAAGGTGTGTGTGTGTGTGTGTG	45
90_H-D-Y	GTATGAGCAATCGAAGCACCAGTTGGCTCTCTCTCTCTCTCTCTC	45
180_I-C-X	TCCCAAGCAGATCCGTGAATAAGACGGTGTGTGTGTGTGTGTGTG	45
180_J-A-Y	ACAGGTGAAGCATATAAGCTGCTCTGCTCTCTCTCTCTCTCTCTC	45
-90_K-D-X	CAAACCACAATCGAAGCACCAGTTGGGTGTGTGTGTGTGTGTGTG	45
-90_L-B-Y	AGCAGATGTCGACTCACGATCGCAAGCTCTCTCTCTCTCTCTCTC	45