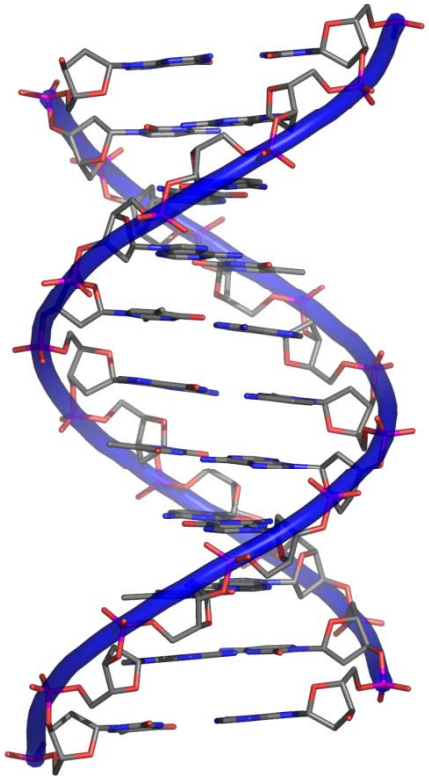
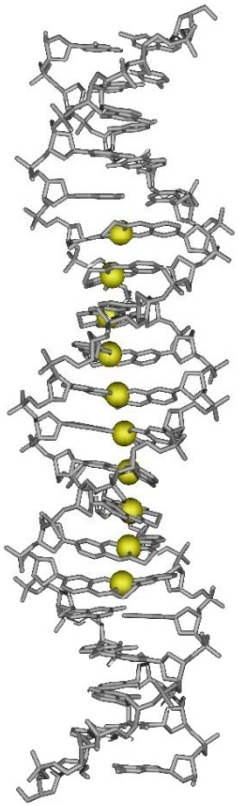
Metals in and around DNA



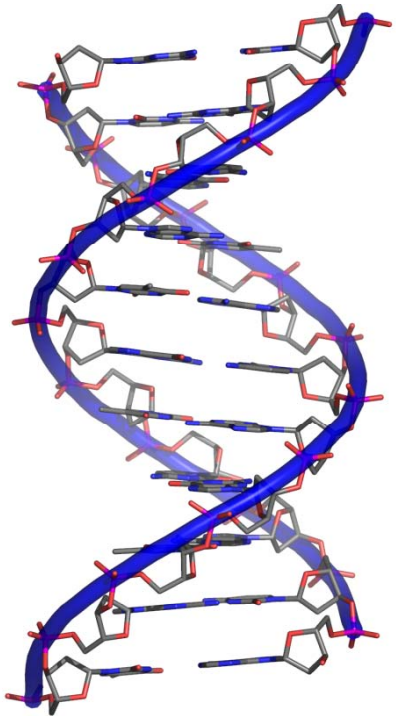
Thomas Carell
LMU Munich
Department of Chemistry
and Biochemistry

…conductivity, magnetic properties, DNA as a catalyst…

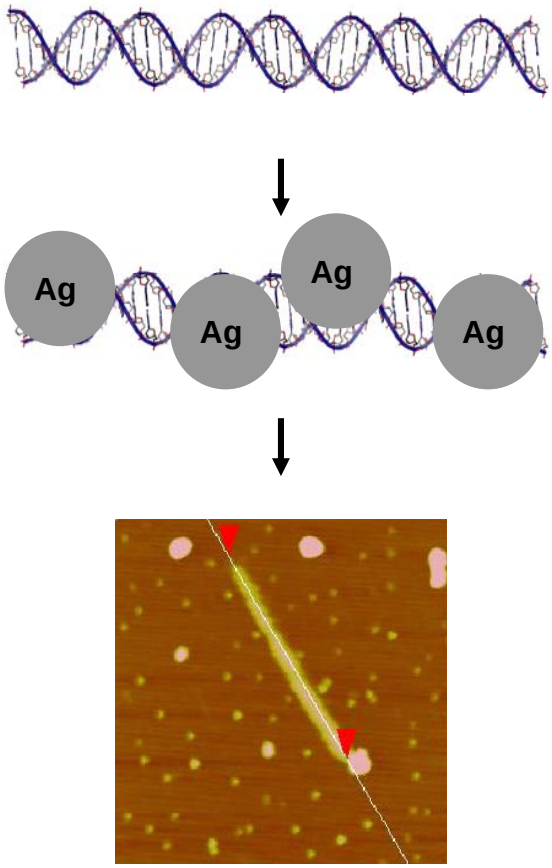
DNA as a multidentate ligand



DNA Catalyst or Wires

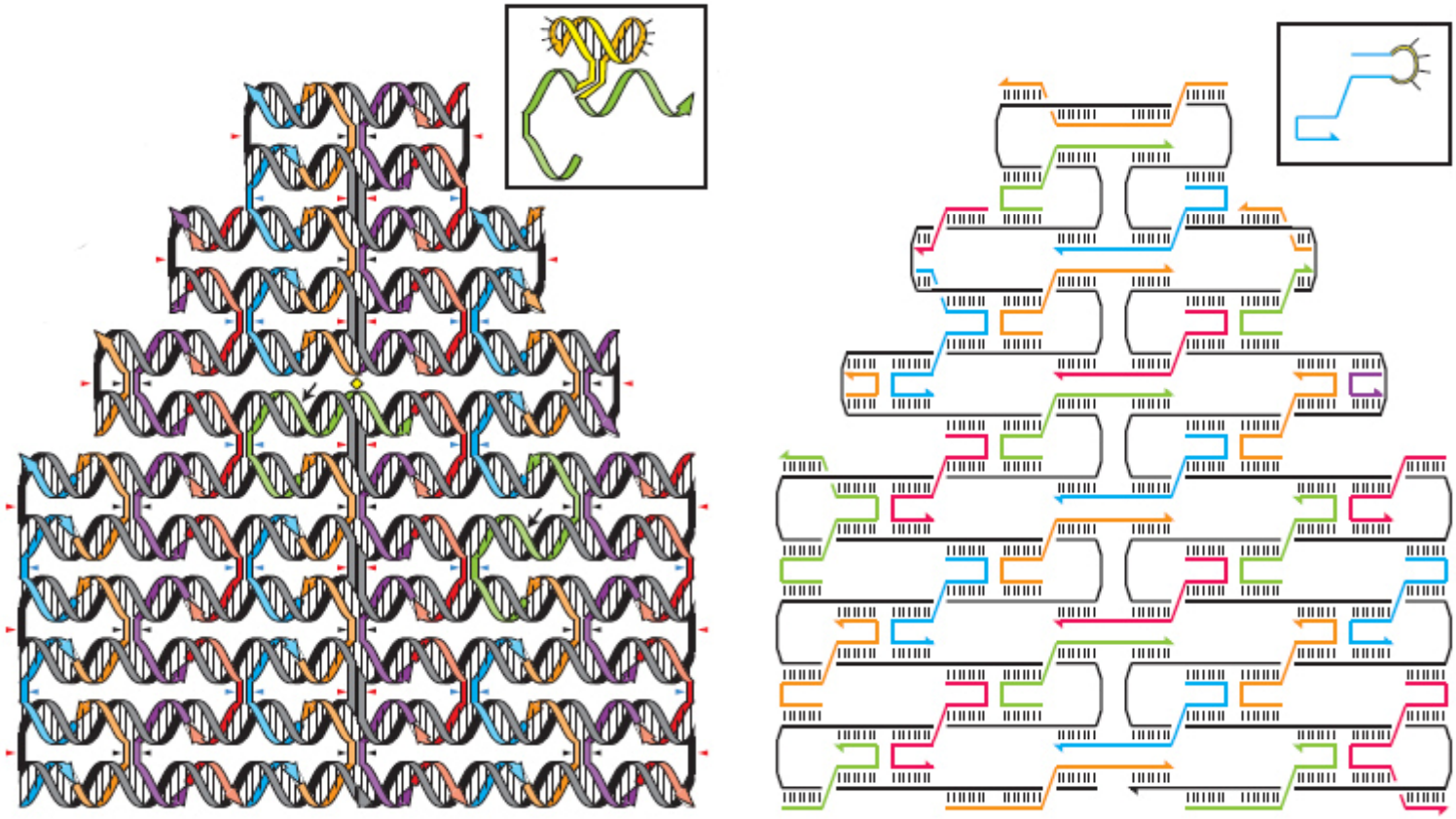


DNA as a template



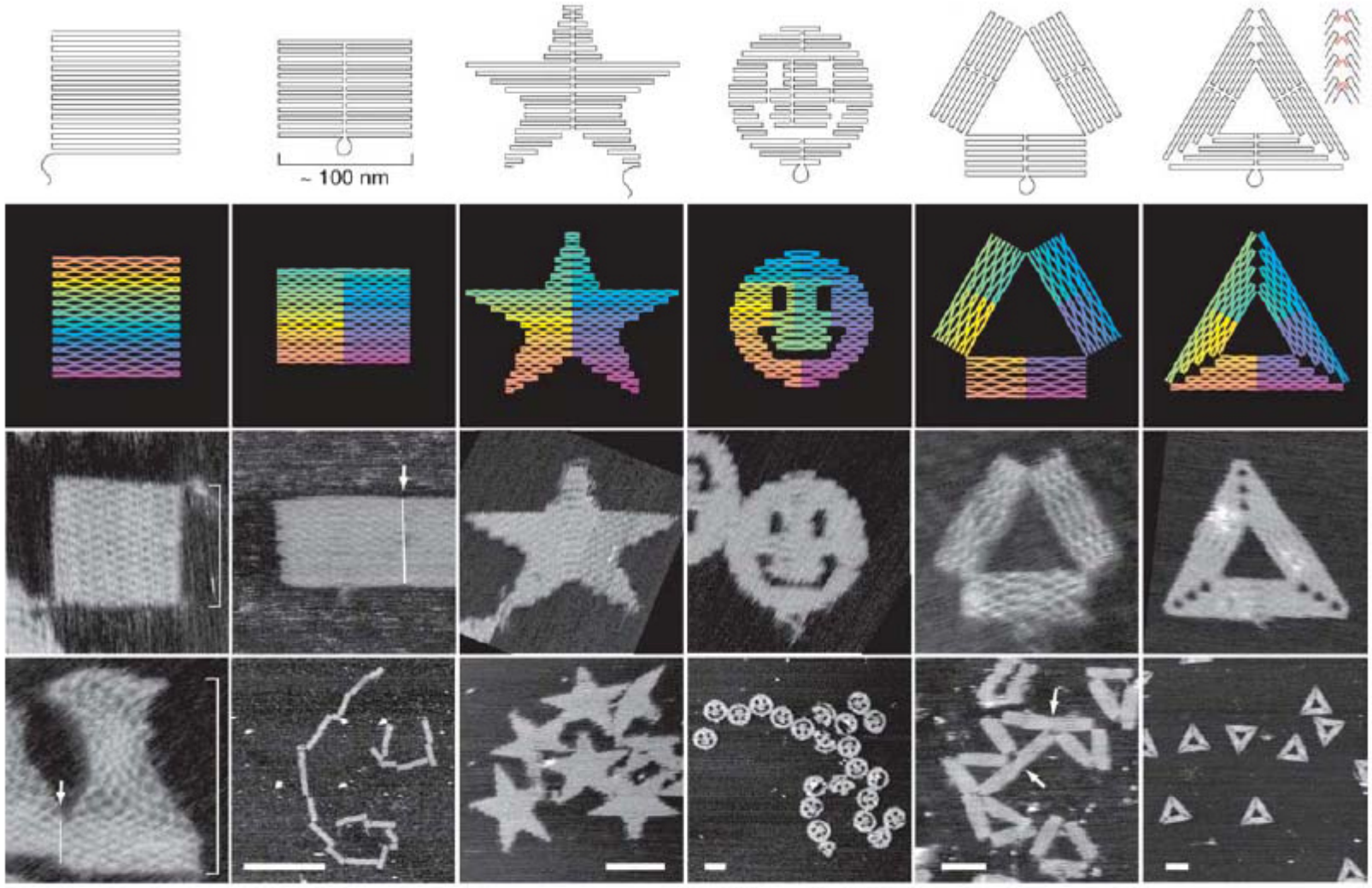
DNA Nanowires in Devices

Constructing the nanoworld from DNA



N. Seeman, the famous cube
P. W. K. Rothemund, *Nature* **2006**, *440*, 297-302

The self recognizing information in DNA allows the assembly of complex nanostructures / architectures

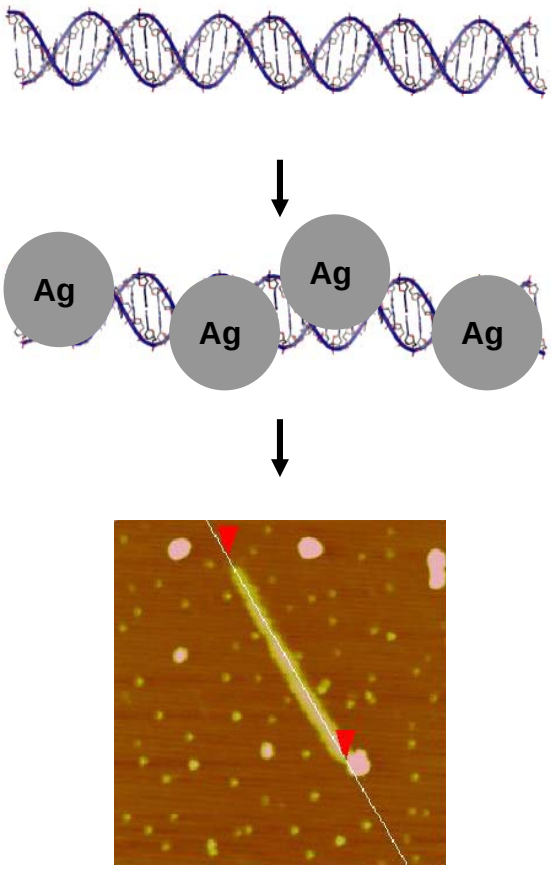


…conductivity, magnetic properties, DNA as a catalyst…

Collaboration between

Carell at LMU Munich
Simon at RWTH Aachen
Eichen at the Technion, Israel
Mayer at RWTH Aachen

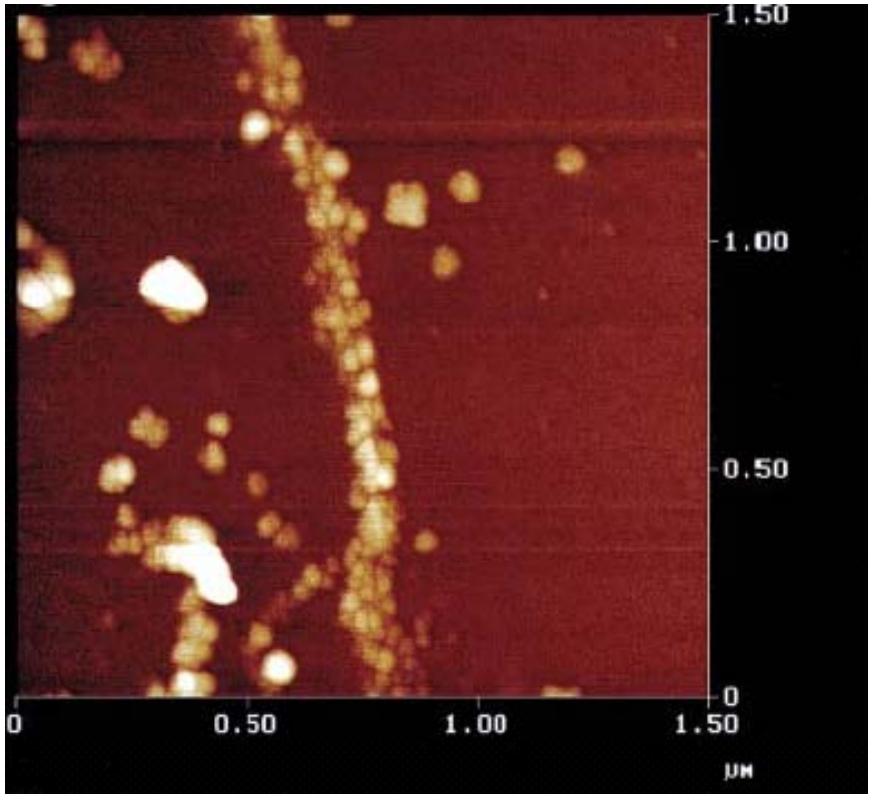
DNA as a Template



DNA nanowires

How can we make DNA conductive?

Coat with a metal film !

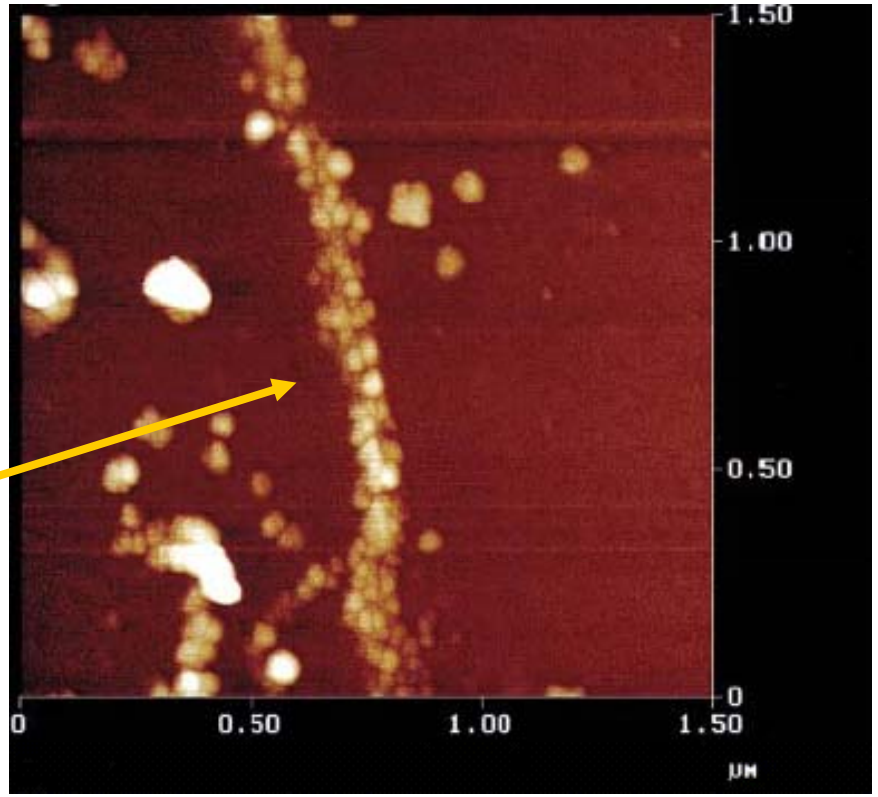


Braun, Eichen, Sivan *et al.*, *Nature***, 1998**, *391*, 775.
Keren *et al.*, *Nano Lett.*, **2004**, *4*, 323.

How can we make DNA conductive?

Coat with a metal film !

Limit metallization to the DNA strand



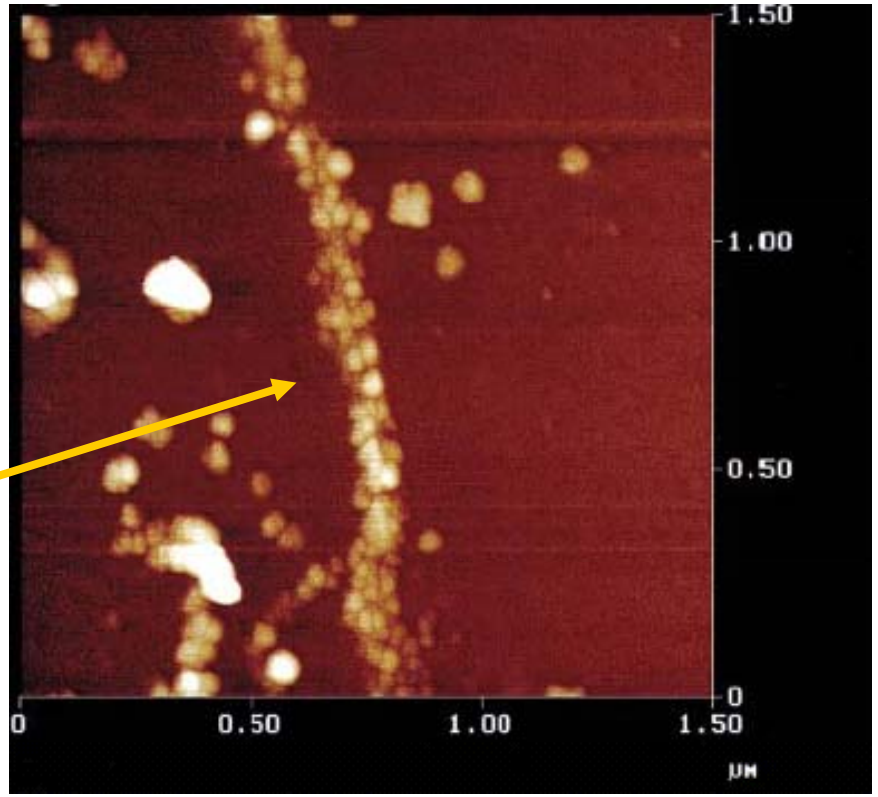
Braun, Eichen, Sivan *et al.*, *Nature*, **1998**, *391*, 775.
Keren *et al.*, *Nano Lett.*, **2004**, *4*, 323.

How can we make DNA conductive?

Coat with a metal film !

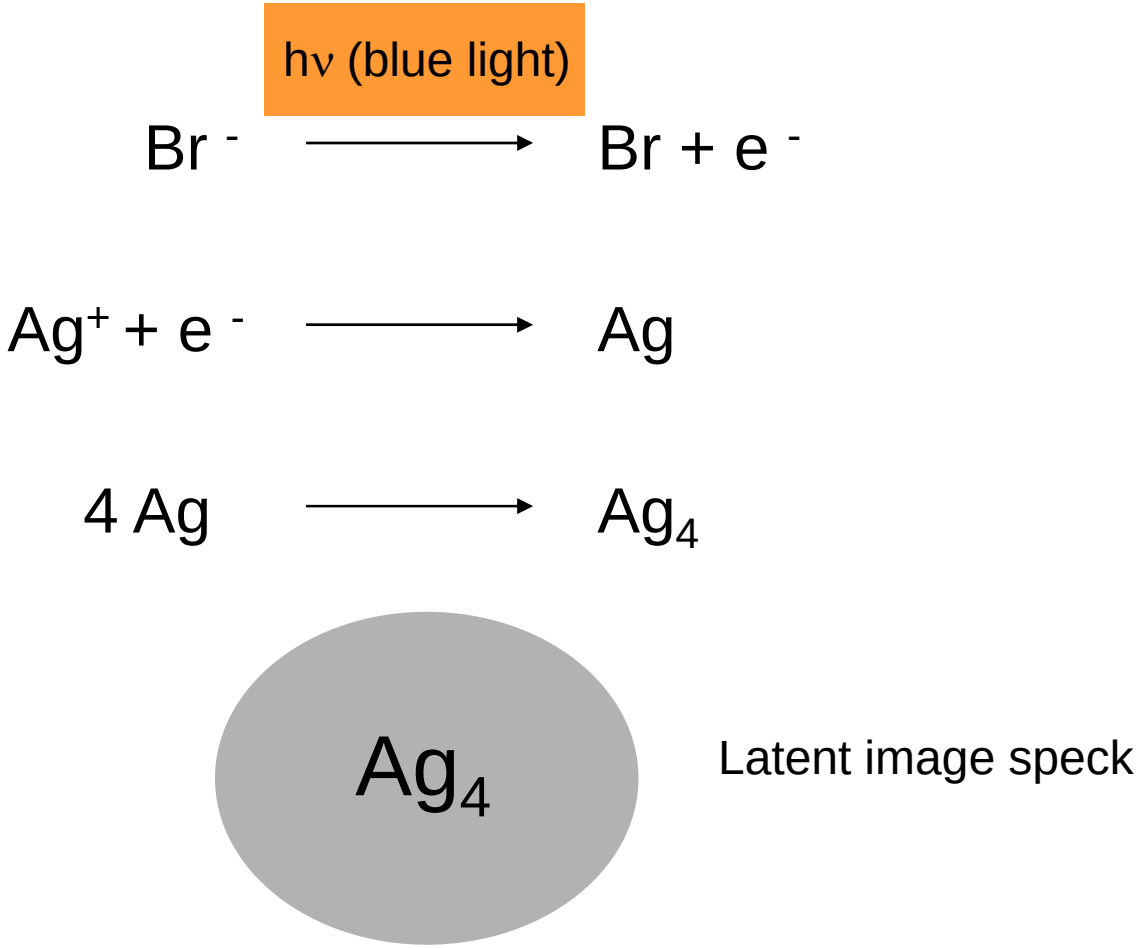
Limit metallization to the DNA strand

Use principles of
black and white photography

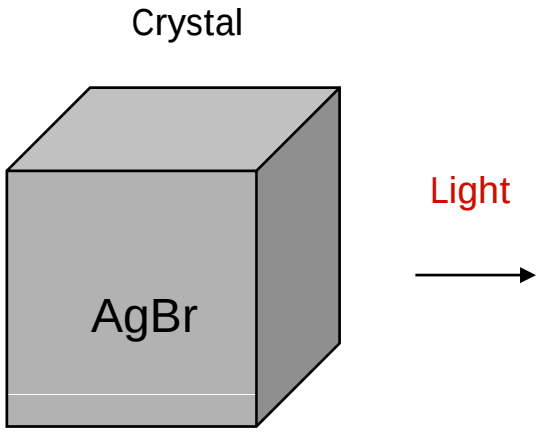


Braun, Eichen, Sivan *et al.*, *Nature*, **1998**, *391*, 775.
Keren *et al.*, *Nano Lett.*, **2004**, *4*, 323.

The chemistry behind black and white photography (1. Step)



Black & White Photography:
Physical development deposition of Ag^+ from solution



J. Eggert: *Wissenschaftliche Photographie*, Verlag O. Helwich, Darmstadt 1958, p. 328.
R. Matejec, R. Meyer, Z. Wiss. Photogr. Photophys. Photochem. **57** (1963) 45.
R. Matejec, Photogr. Korresp. **107** (1971) no. 3, 37.
R. Matejec, J. Signalaufzeichnungsmat. **3** (1975) 219.

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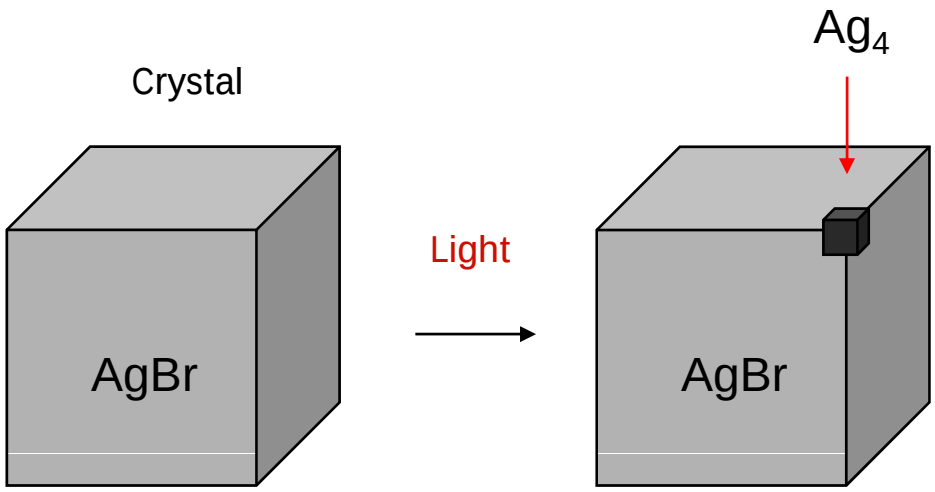

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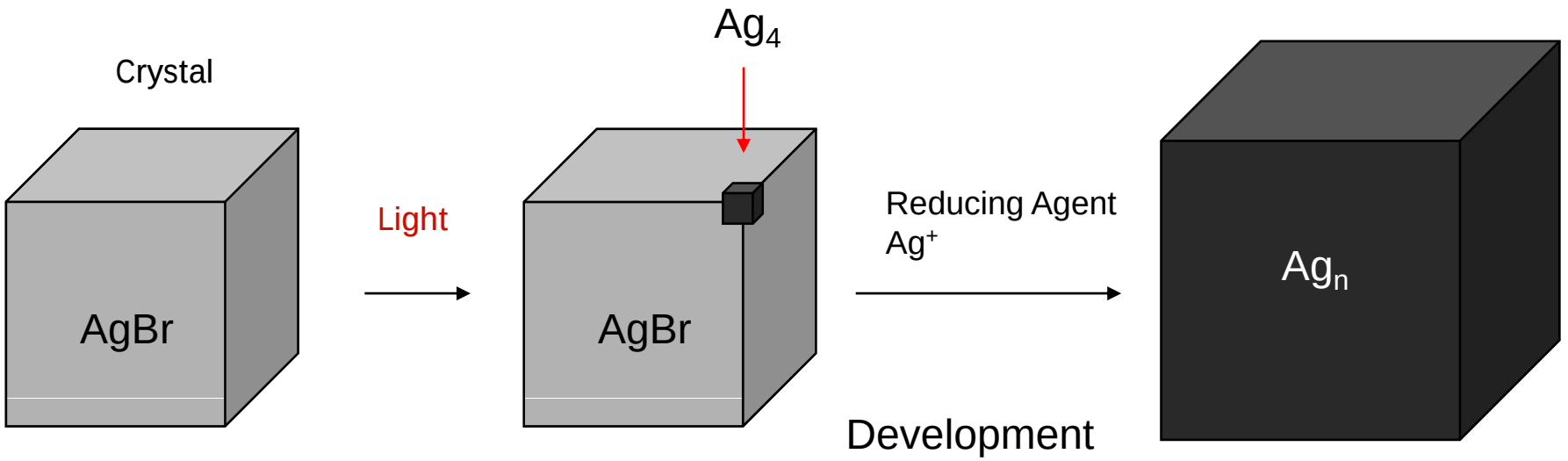

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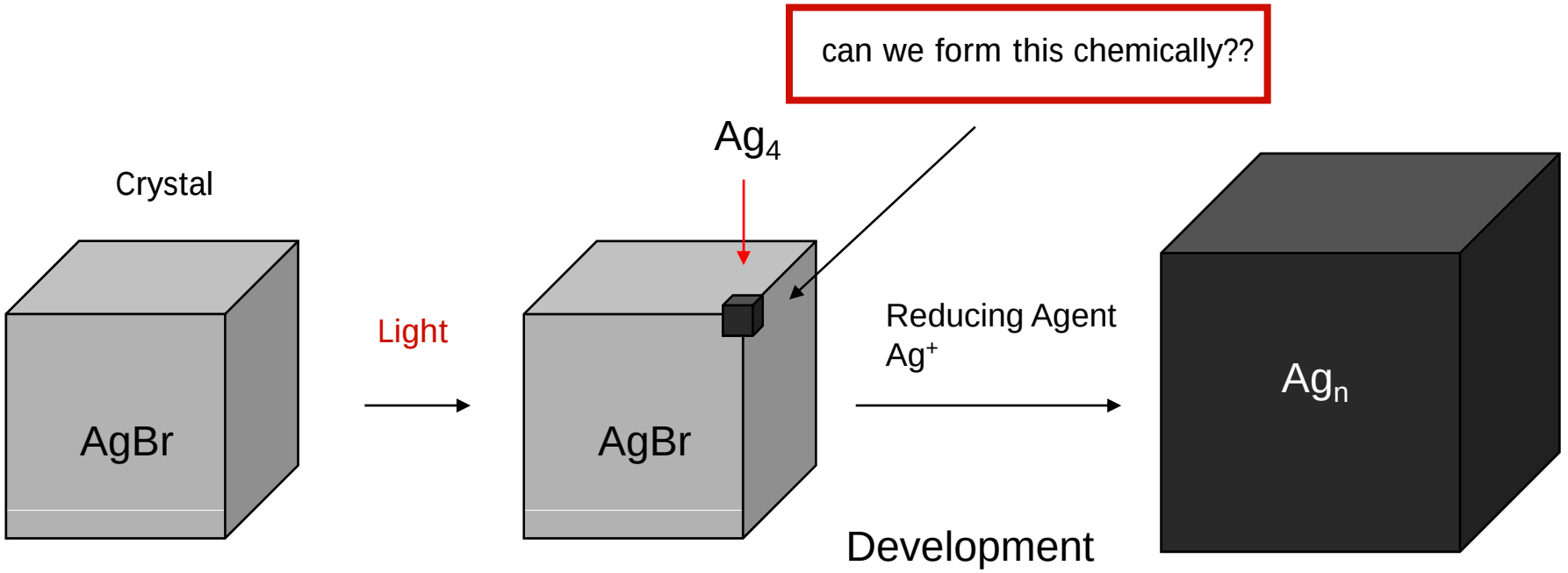
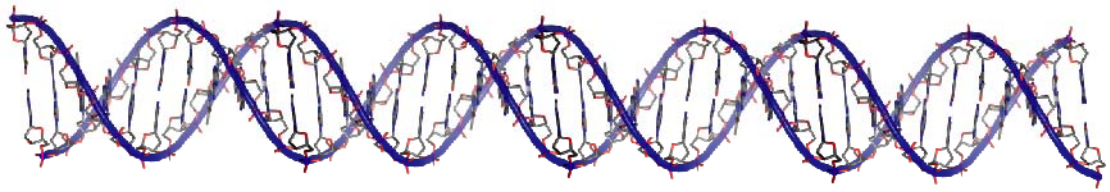
R. Matejec, J. Signalaufzeichnungsmat. **3** (1975) 219.

Physical Development
Deposition of Ag^+ from solution



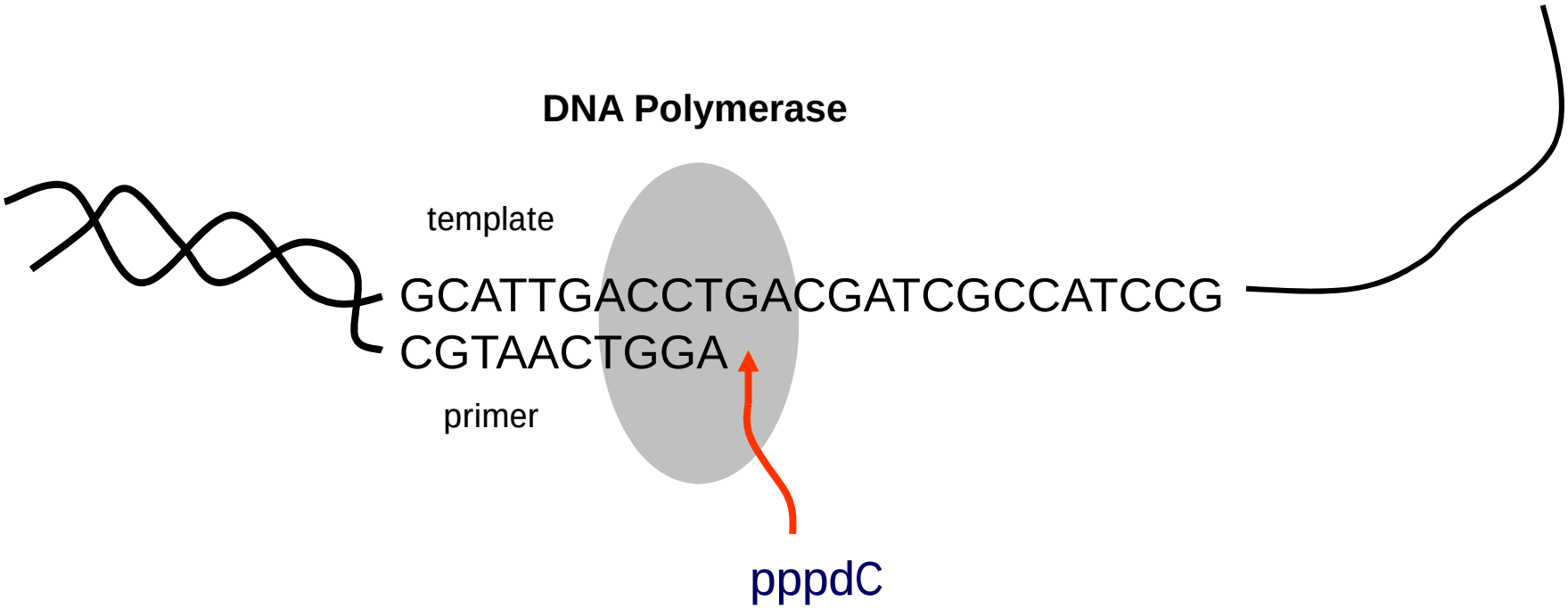
J. Eggert: *Wissenschaftliche Photographie*, Verlag O. Helwich, Darmstadt 1958, p. 328.
R. Matejec, R. Meyer, Z. Wiss. Photogr. Photophys. Photochem. **57** (1963) 45.
R. Matejec, Photogr. Korresp. **107** (1971) no. 3, 37.
R. Matejec, J. Signalaufzeichnungsmat. **3** (1975) 219.

DNA metallization to increase conductivity

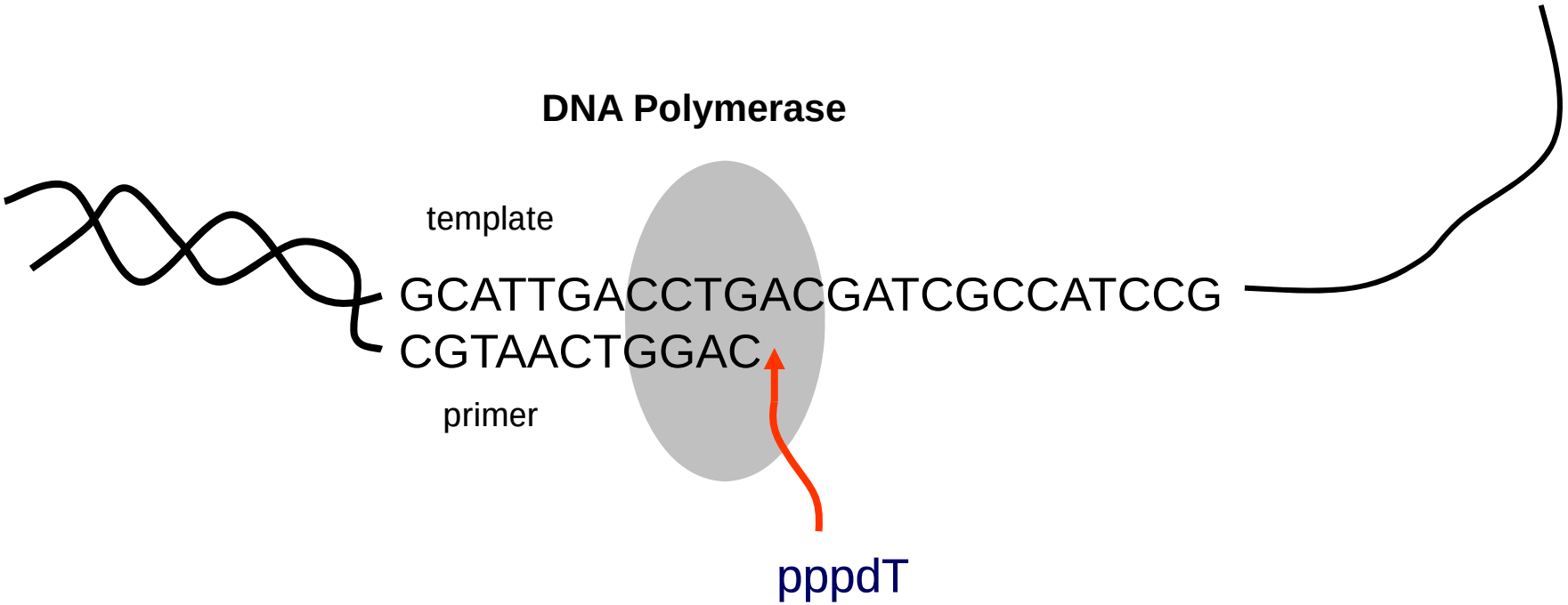


- modify the DNA with reducing groups

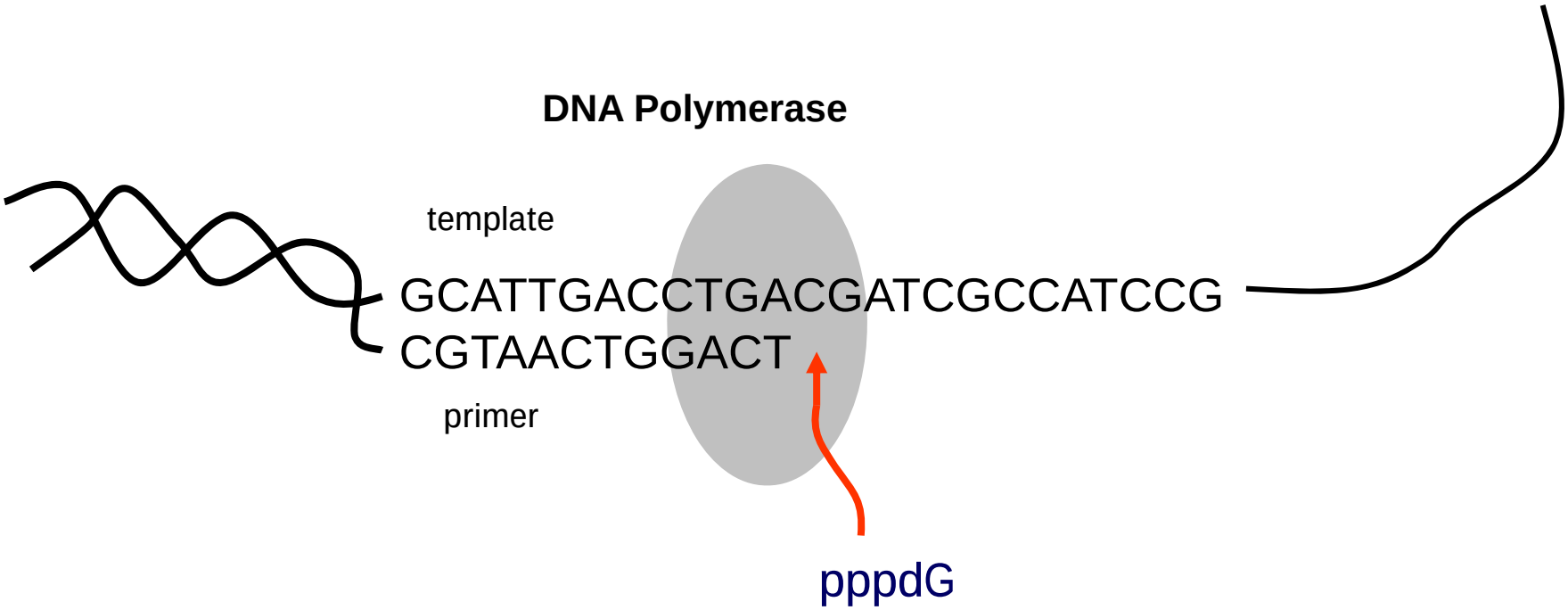
DNA replication
molecular recognition inside a polymerase



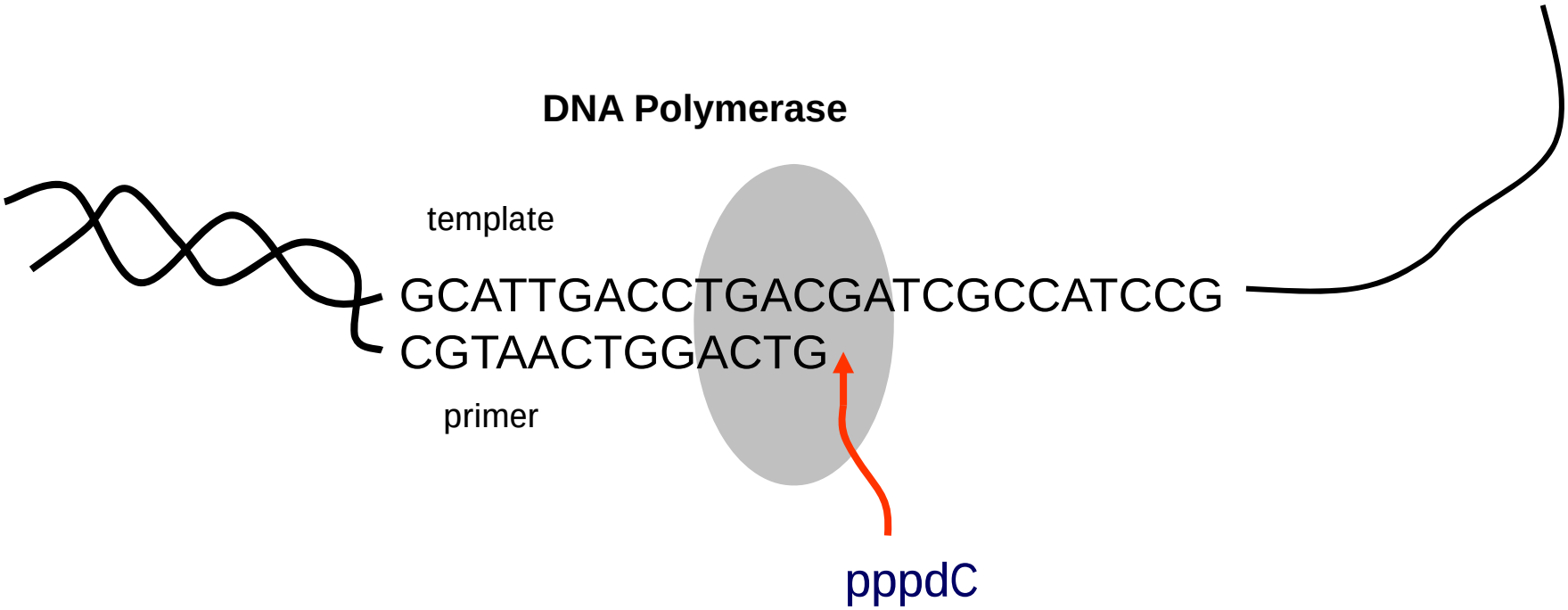
DNA replication
molecular recognition inside a polymerase



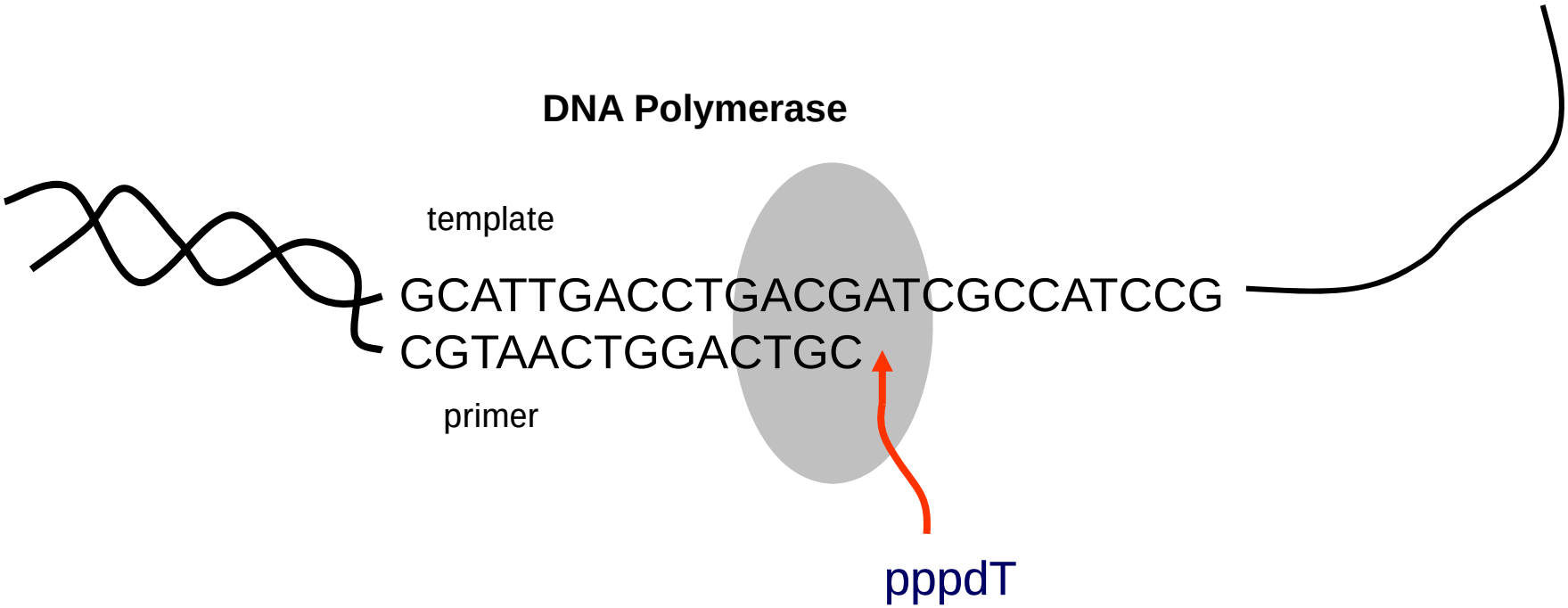
DNA replication
molecular recognition inside a polymerase



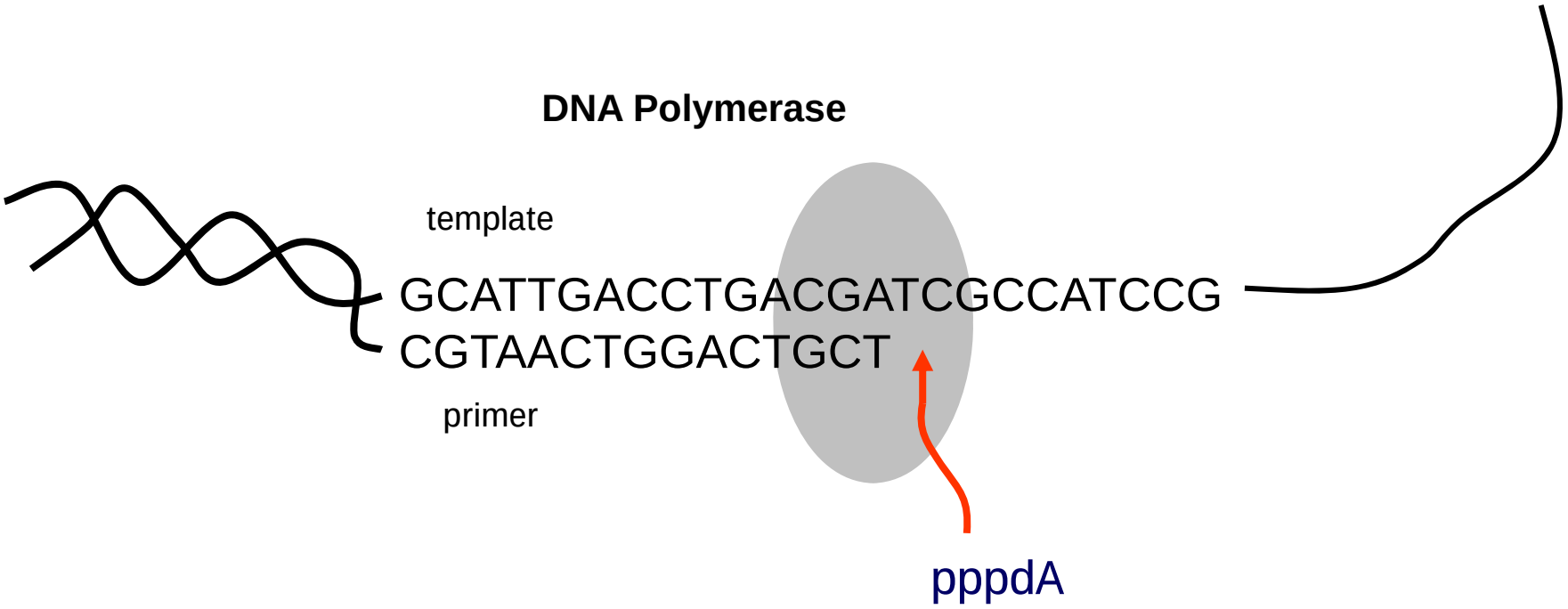
DNA replication
molecular recognition inside a polymerase



DNA replication
molecular recognition inside a polymerase



DNA replication
molecular recognition inside a polymerase



DNA replication
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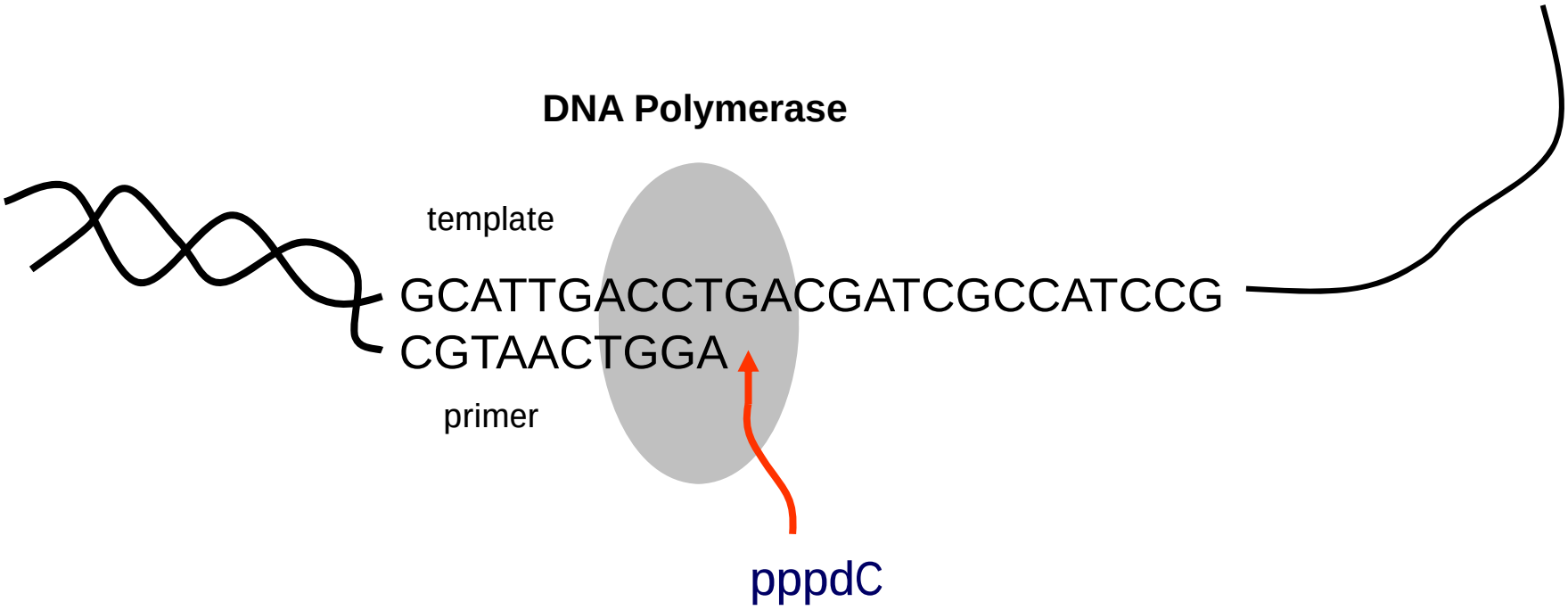
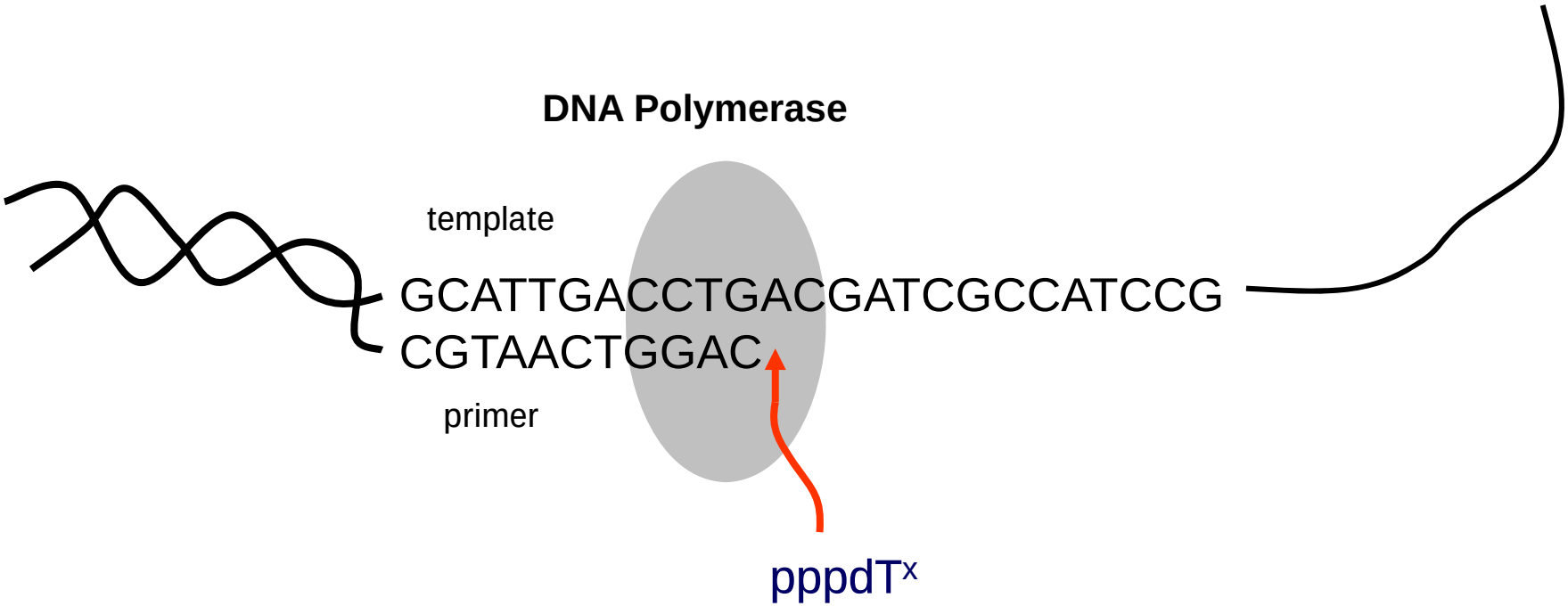
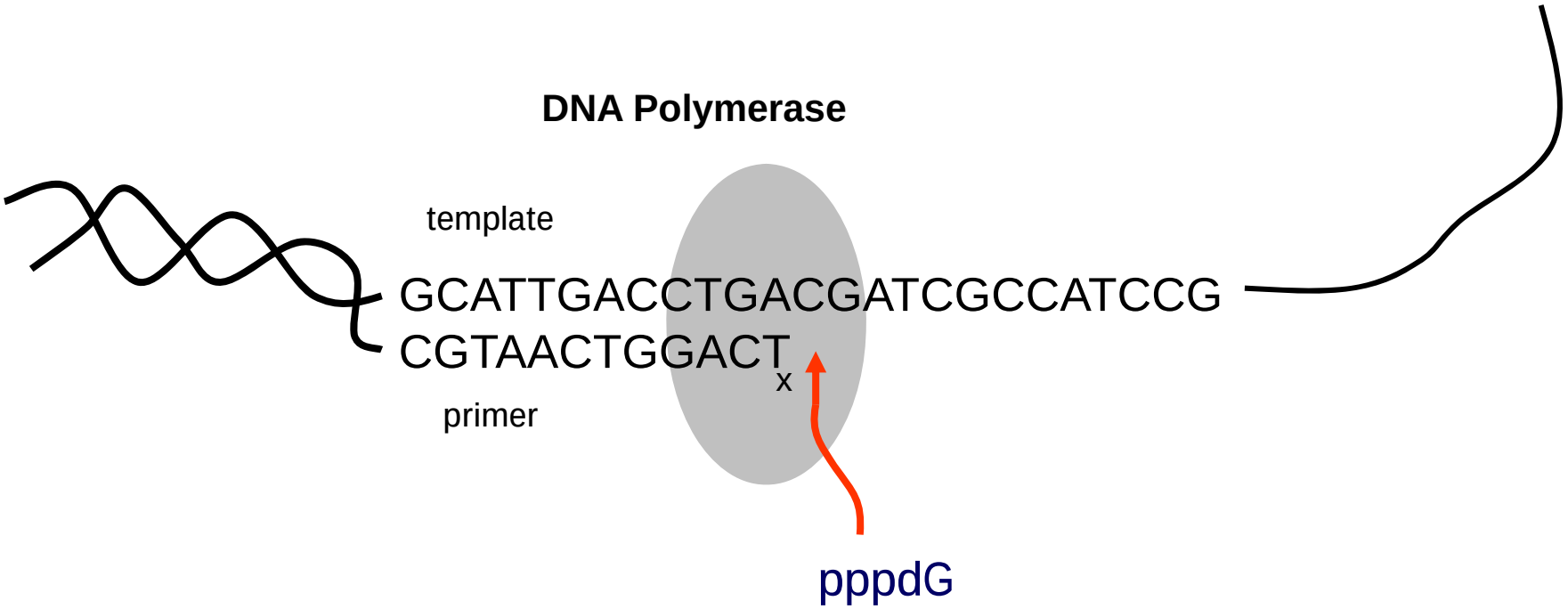


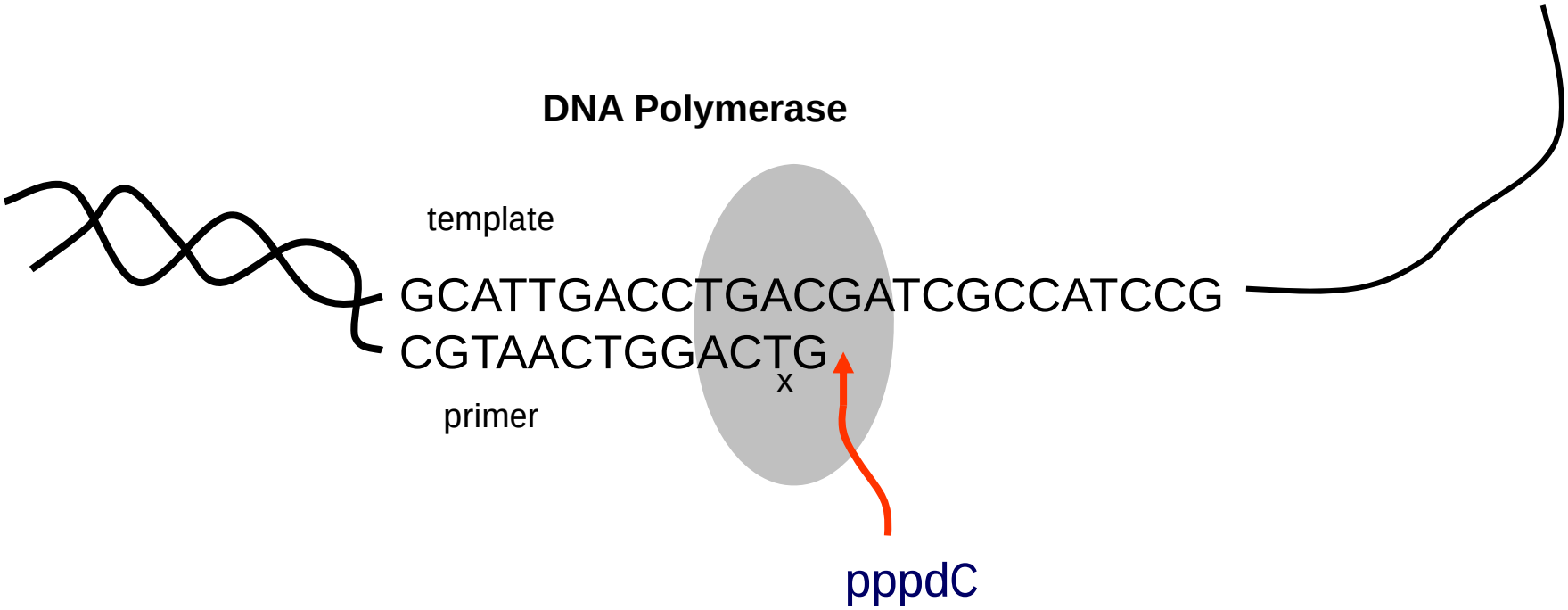
DNA replication
molecular recognition inside a polymerase



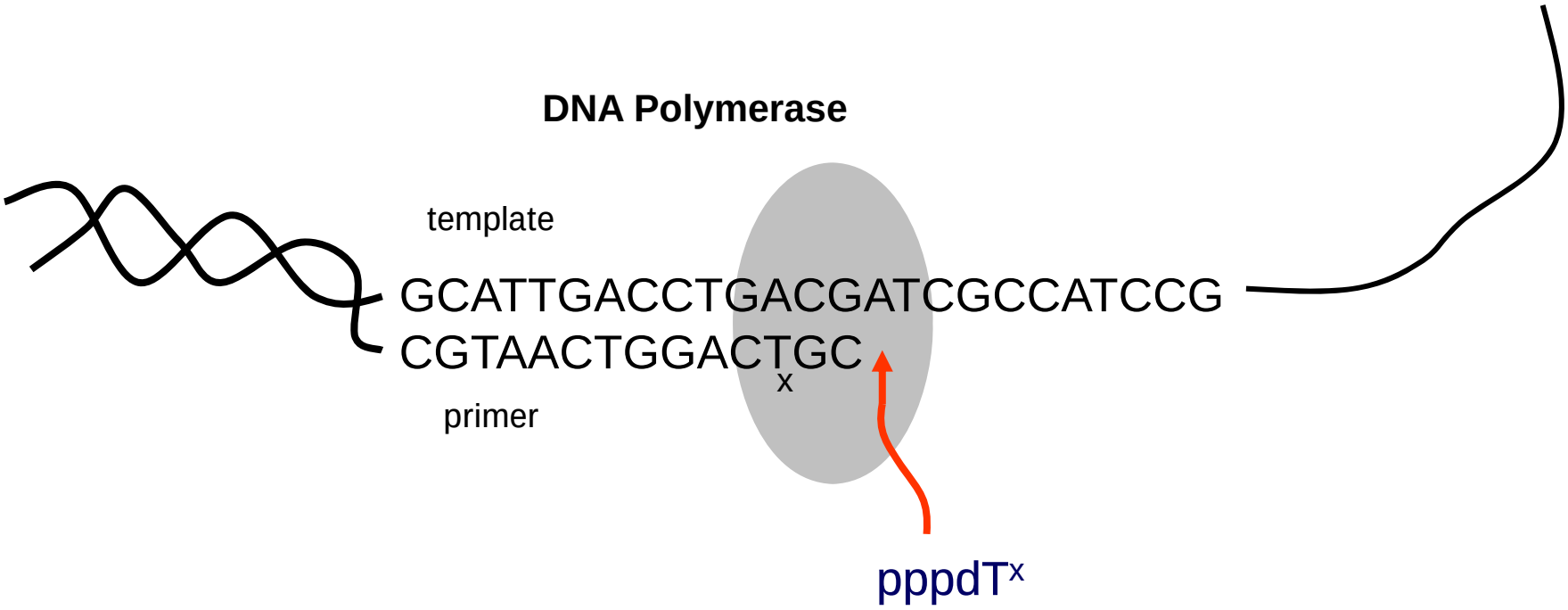
DNA replication
molecular recognition inside a polymerase



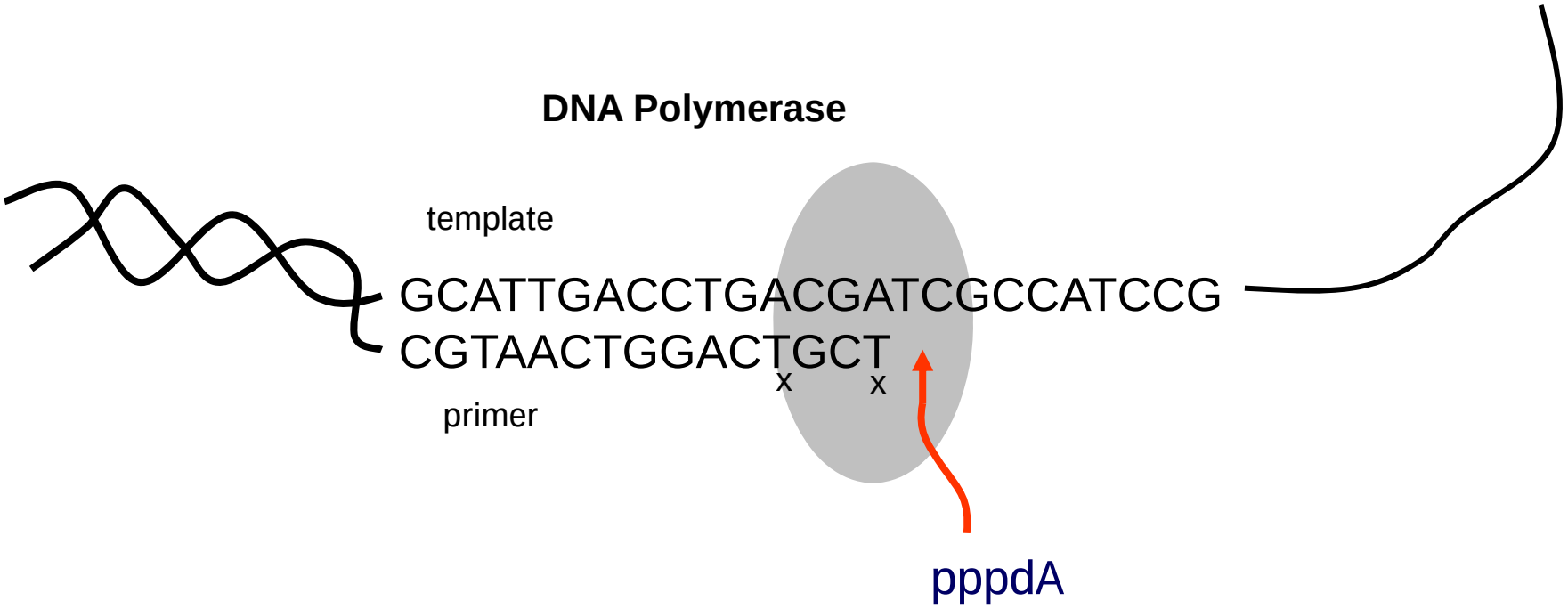
DNA replication
molecular recognition inside a polymerase



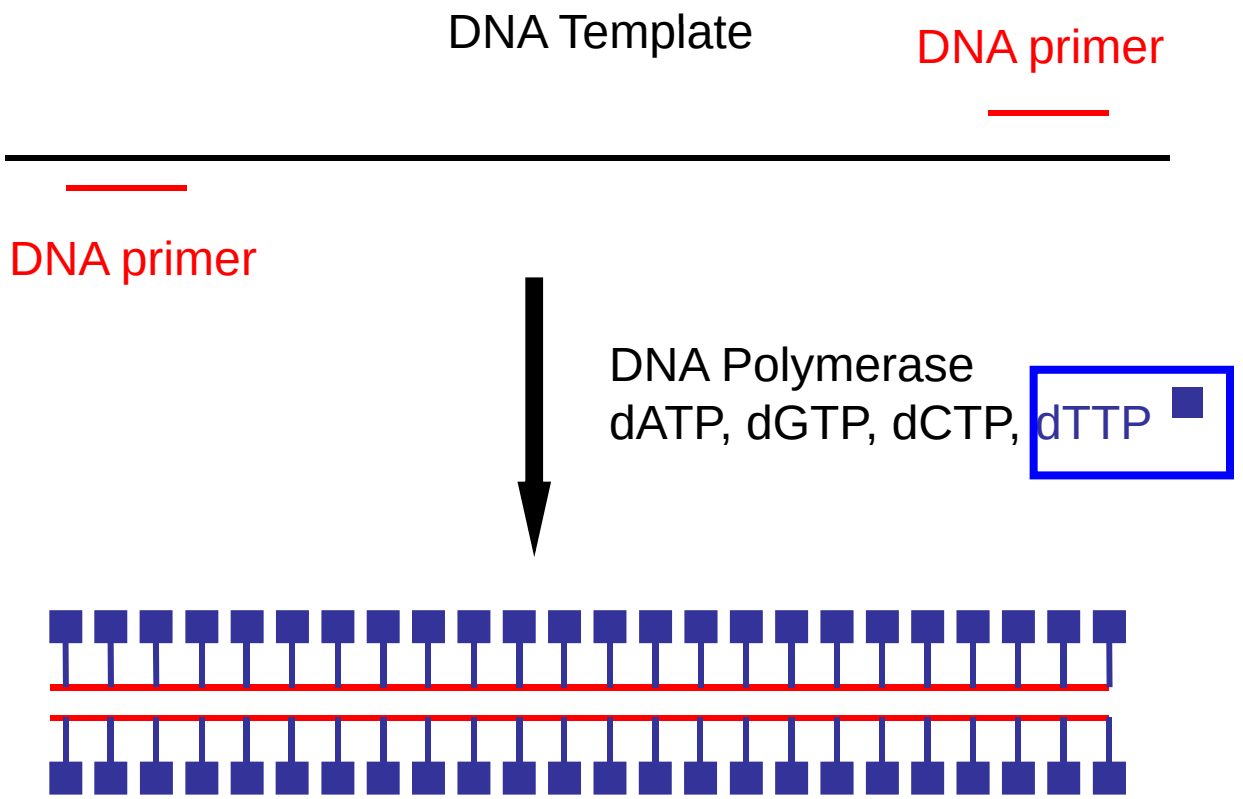
DNA replication
molecular recognition inside a polymerase



DNA replication
molecular recognition inside a polymerase

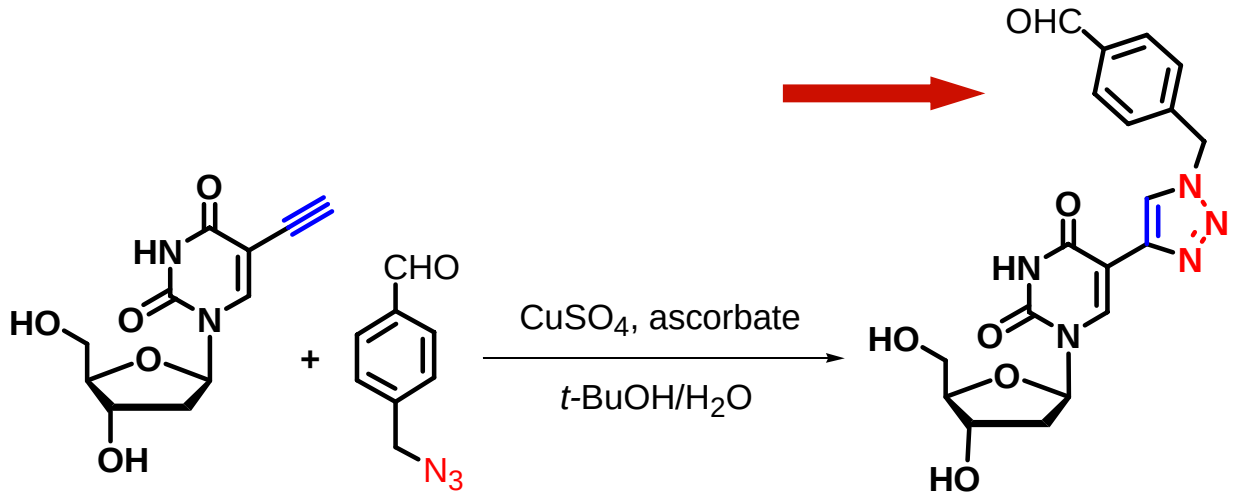


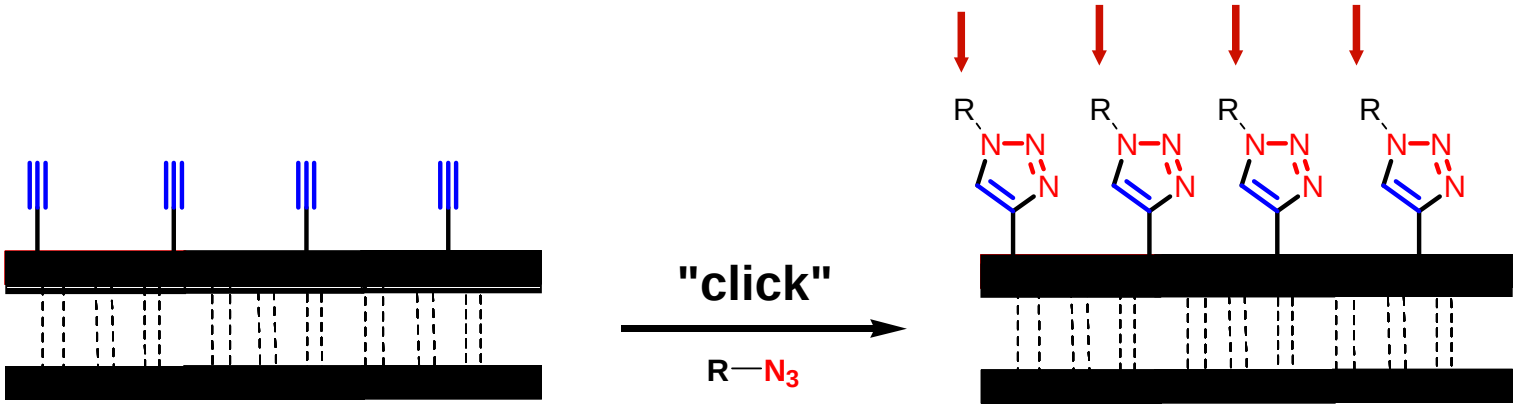
Use molecular biology to construct nanodevices



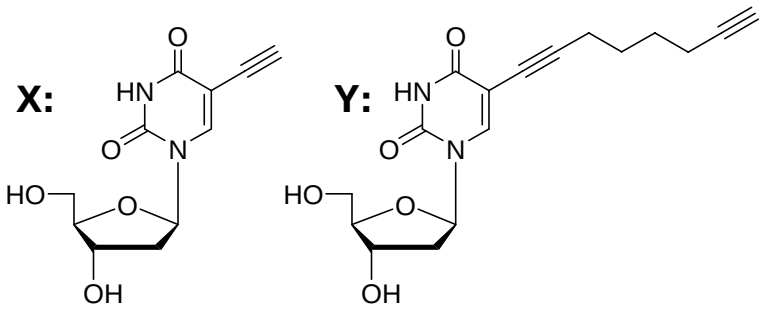
DNA duplexes with up to 2000 bp are accessible in this way !
(around 500 modifications)

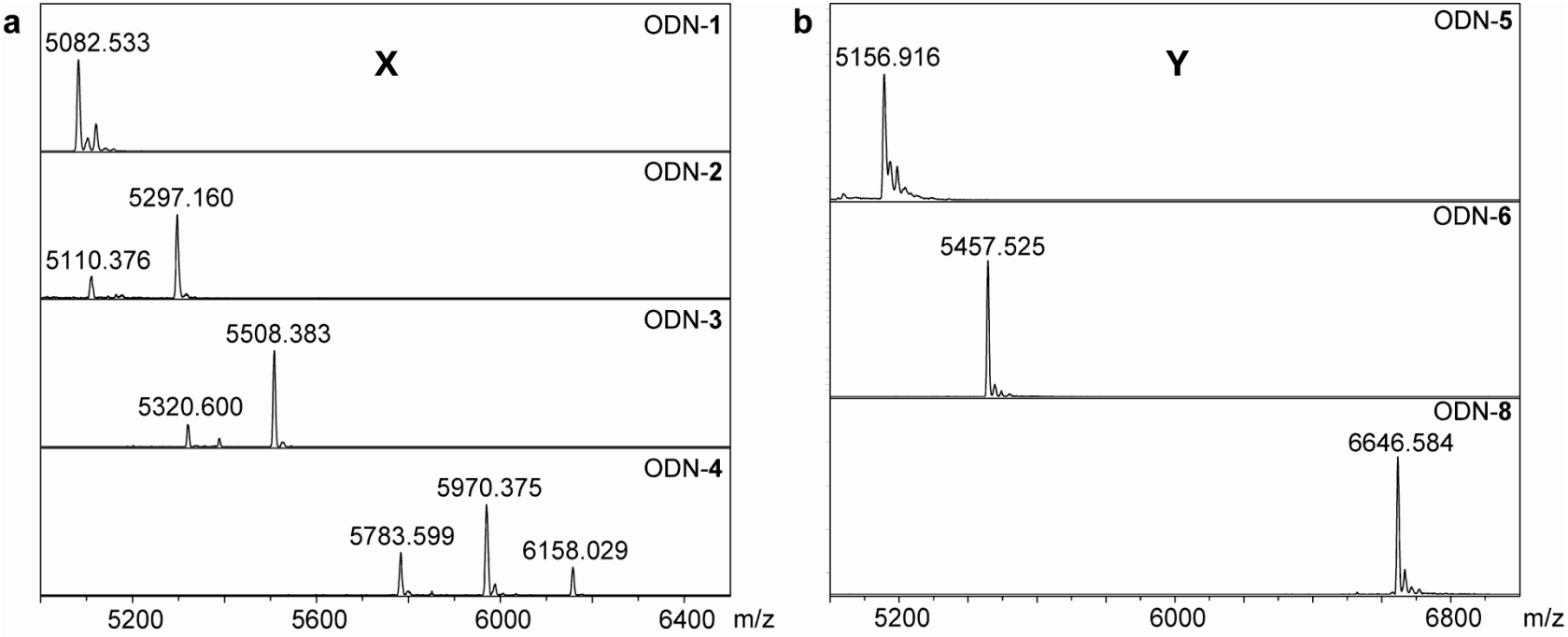
[3+2] cycloaddition (click reaction) to label DNA with aldehydes

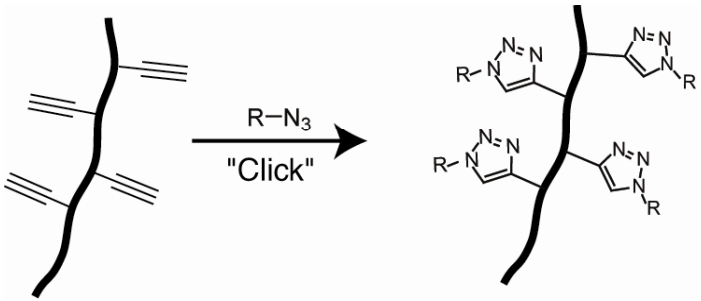




1: 5′-GCG CTG T**X**C ATT CGC G
2: 5′-GCG CTG **XX**C ATT CGC G
3: 5′-GCG C**X**G T**X**C A**X**T CGC G
4: 5′-GCG C**XX XXX X**GT CGC G
5: 5′-GCG CTG T**Y**C ATT CGC G
6: 5′-GCG CTG **YY**C ATT CGC G
7: 5′-GCG C**Y**G T**Y**C A**Y**T CGC G
8: 5′-GCG C**YY YYY Y**GT CGC G





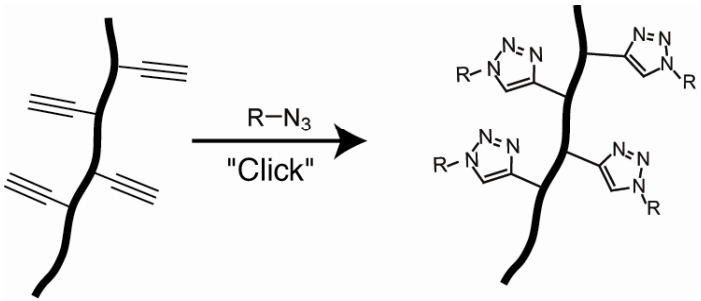


…In the presence of excess azide, a Cu(I) salt and DNA a range of adducts corresponding to strand breaks were observed, suggesting that the original click procedure was not amenable to high density functionalisation of DNA.

*However, using the Cu(I)-stabilising ligand (tris-(benzyltriazolylmethyl)amine),full conversion of both ODN-**1** and ODN-**4** to their respective triazole products was observed …*

Gierlich, Burley, Carell *Org. Lett* **2006**

Click reaction at work



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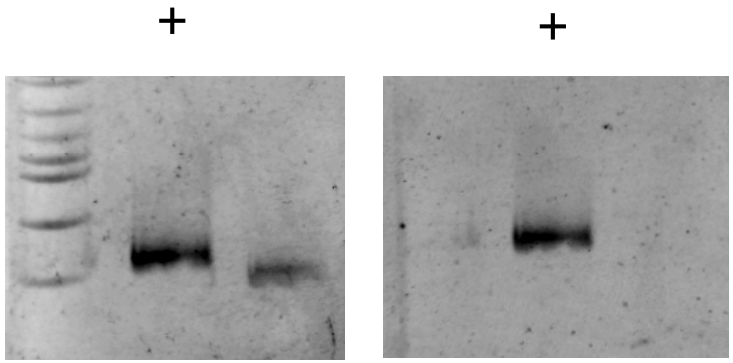
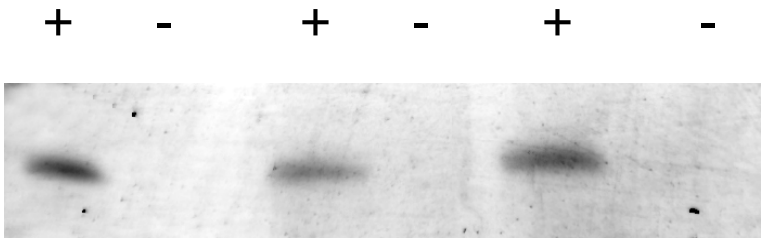
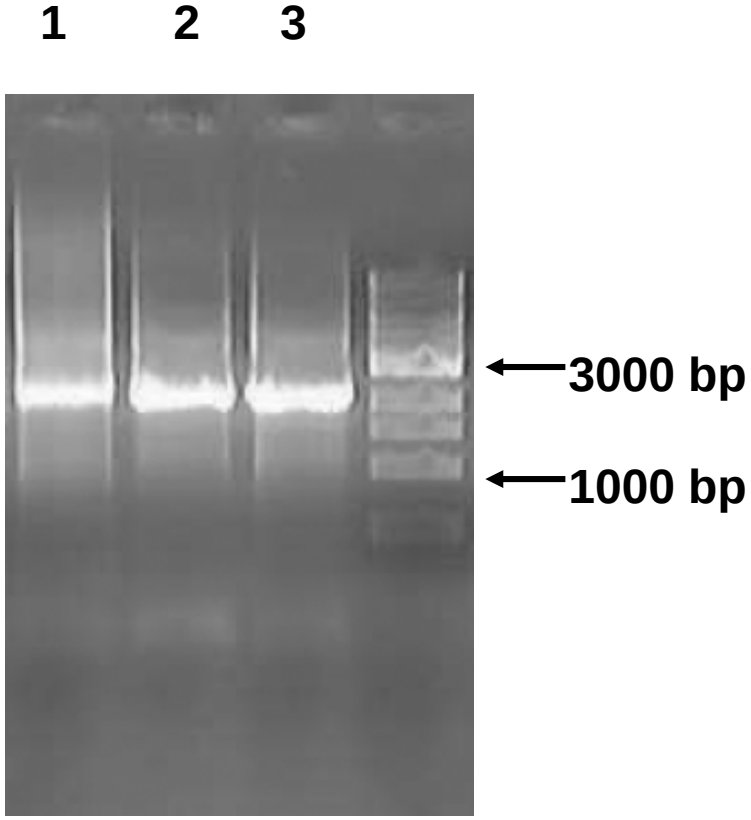
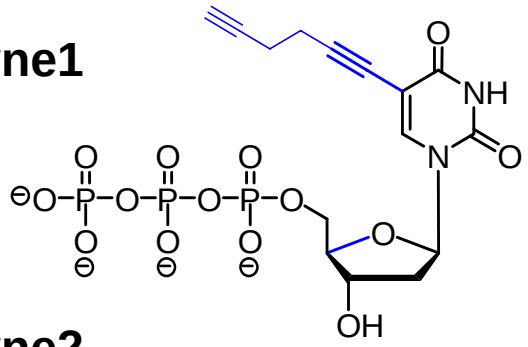




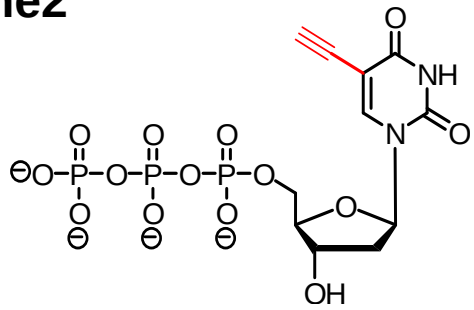
Enzymatic incorporation of building blocks using a high fidelity DNA polymerase



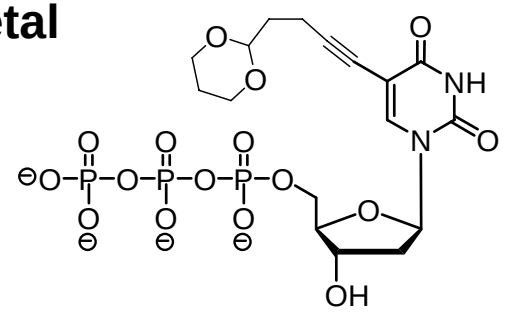
1 dUTP-alkyne1



2 dUTP-alkyne2

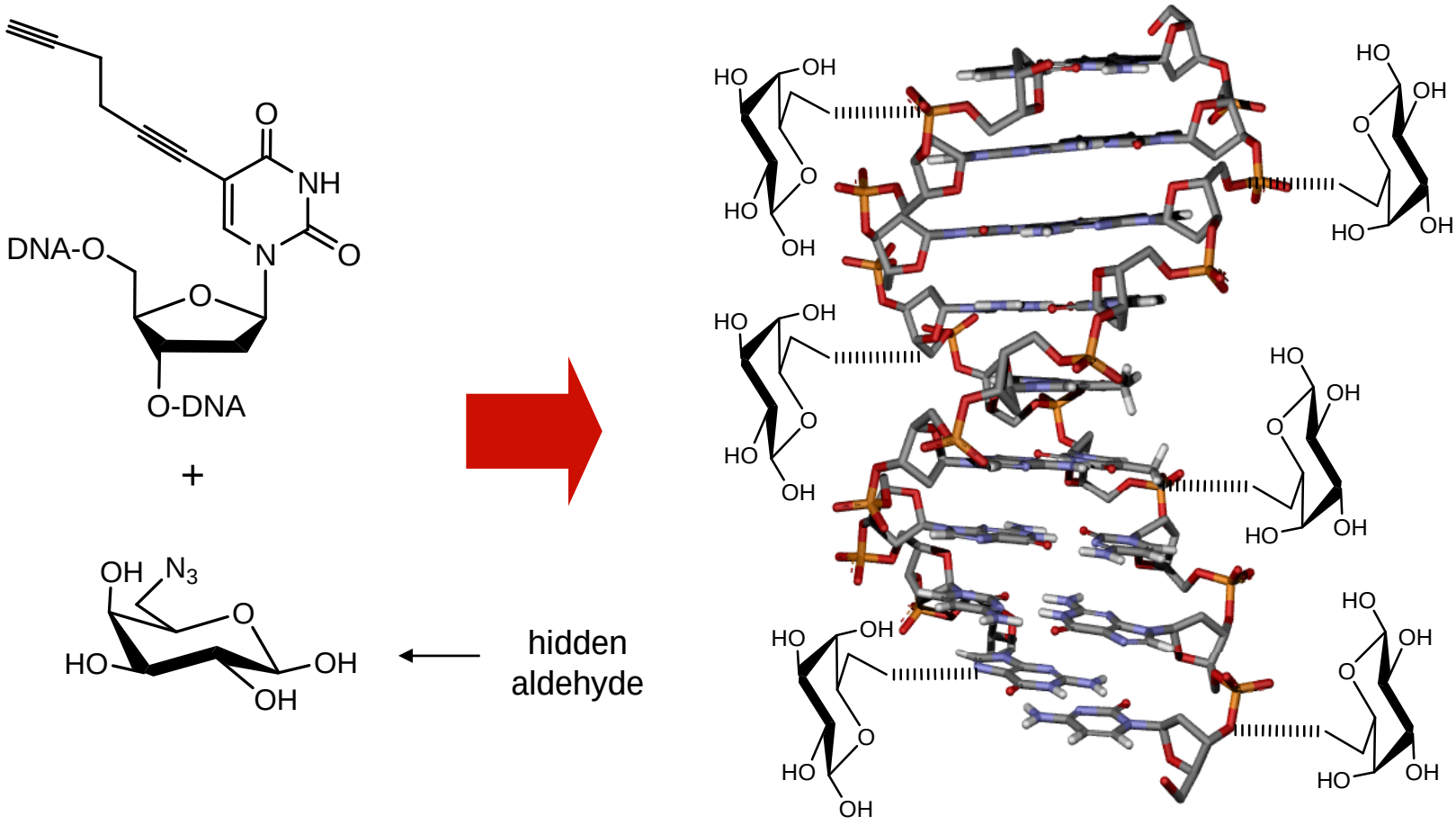


3 dUTP-acetal



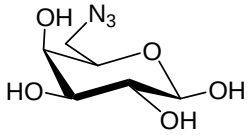
Modified triphosphates are incorporated with the same efficiency compared to thymidine triphosphate.

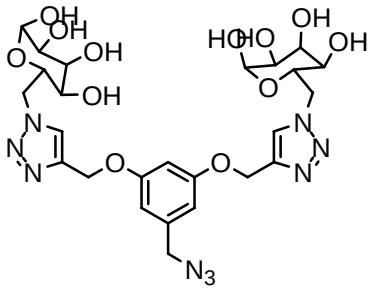
Back to silver staining: Sugar coating of DNA

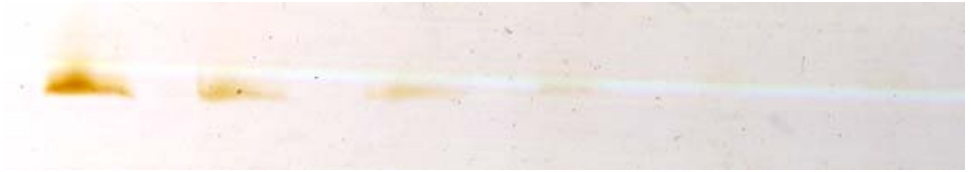


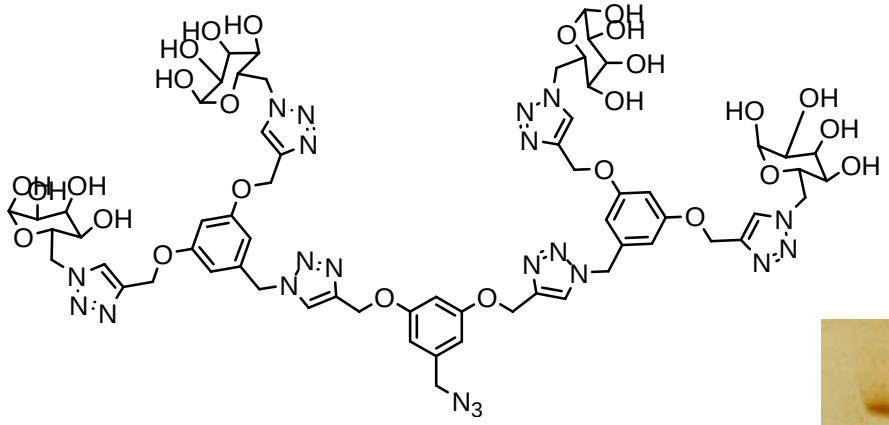
G. A. Burley, J. Gierlich, M. R. Mofid, H. Nir, S. Tal, Y. Eichen, T. Carell. *J. Am. Chem. Soc*. **2006**, *128*. 1398.
Highlighted in *Science*, **2006**, *311*, 437.

Clicking of sugar dendrimers DNA increases metallization



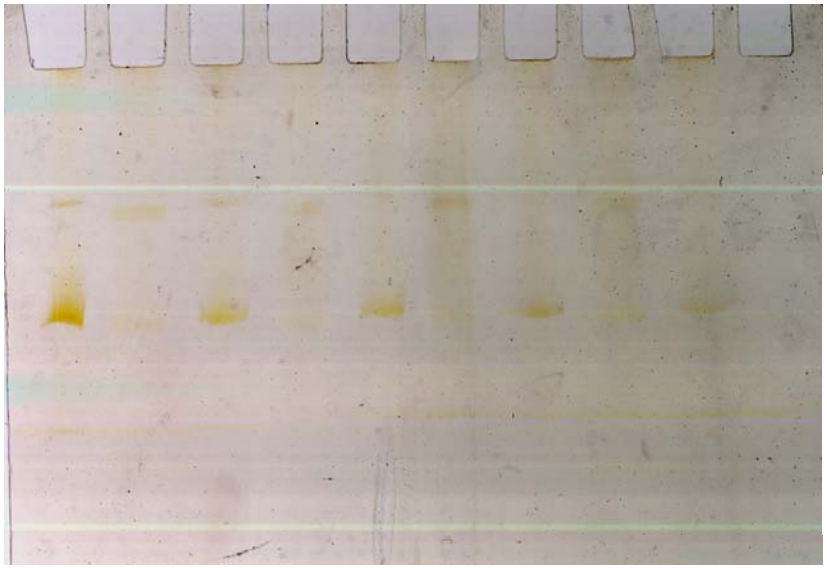




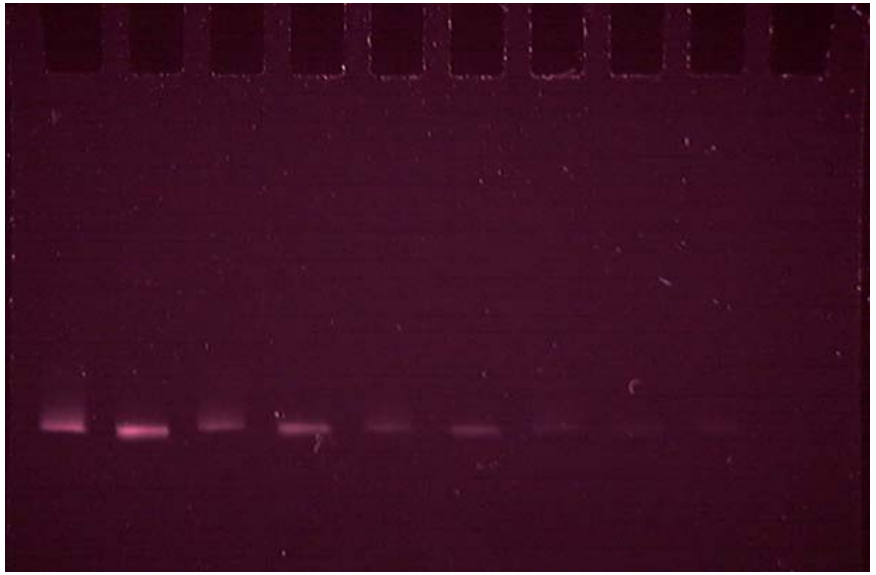


J. Am. Chem. Soc. **2006**

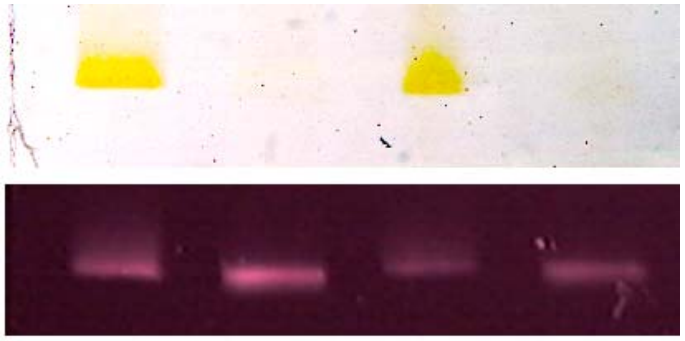
1 2 3 4 5 6 7 8 9 10



1 2 3 4 5 6 7 8 9 10



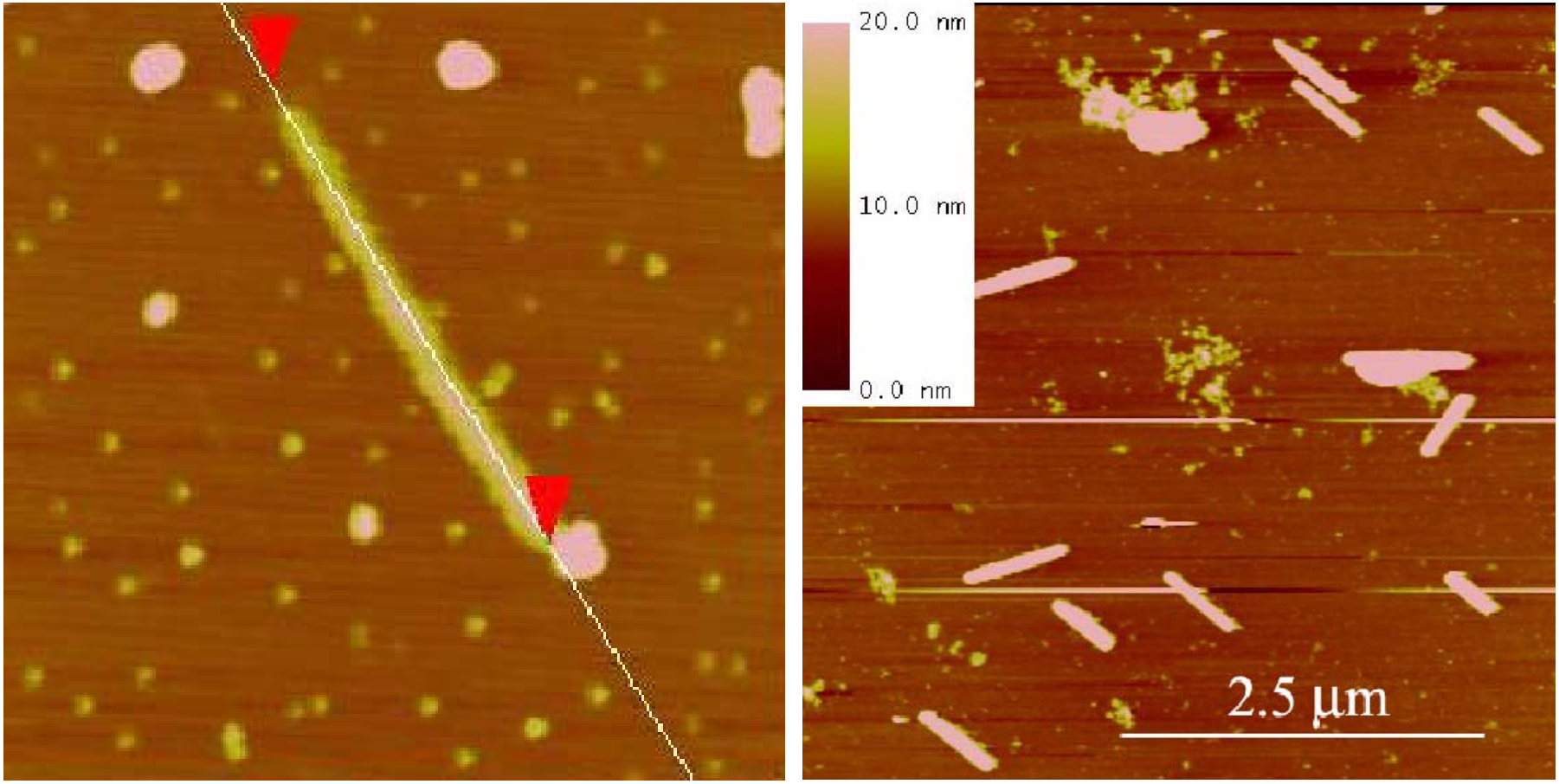
Lane 1, 3, 5, 7, 9: **floppy Alkin 1**: 300 bp. 7 ng, 3.5 ng, 1.75 ng, 0.88 ng, 0.44 nm
Lane 2,4,6,8: **natural DNA**: 300 bp 7 ng, 3.5 ng, 1.75 ng, 0.88 ng



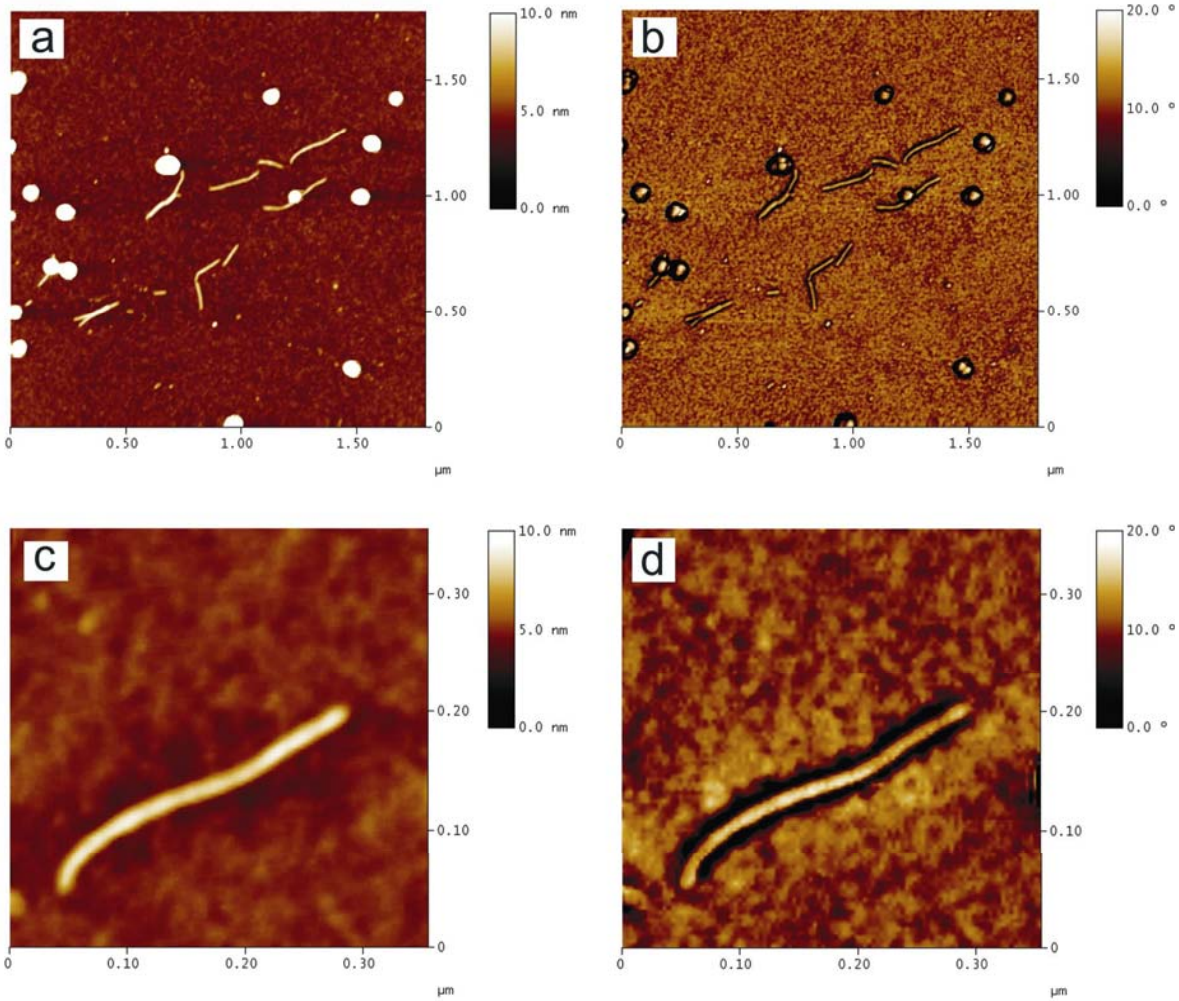
Ag-Staining (down to 100 atomol)
PCR free detection

Fluorescence-Staining

Nano wires templates by sugar coated DNA



Sugar coated DNA after Ag deposition

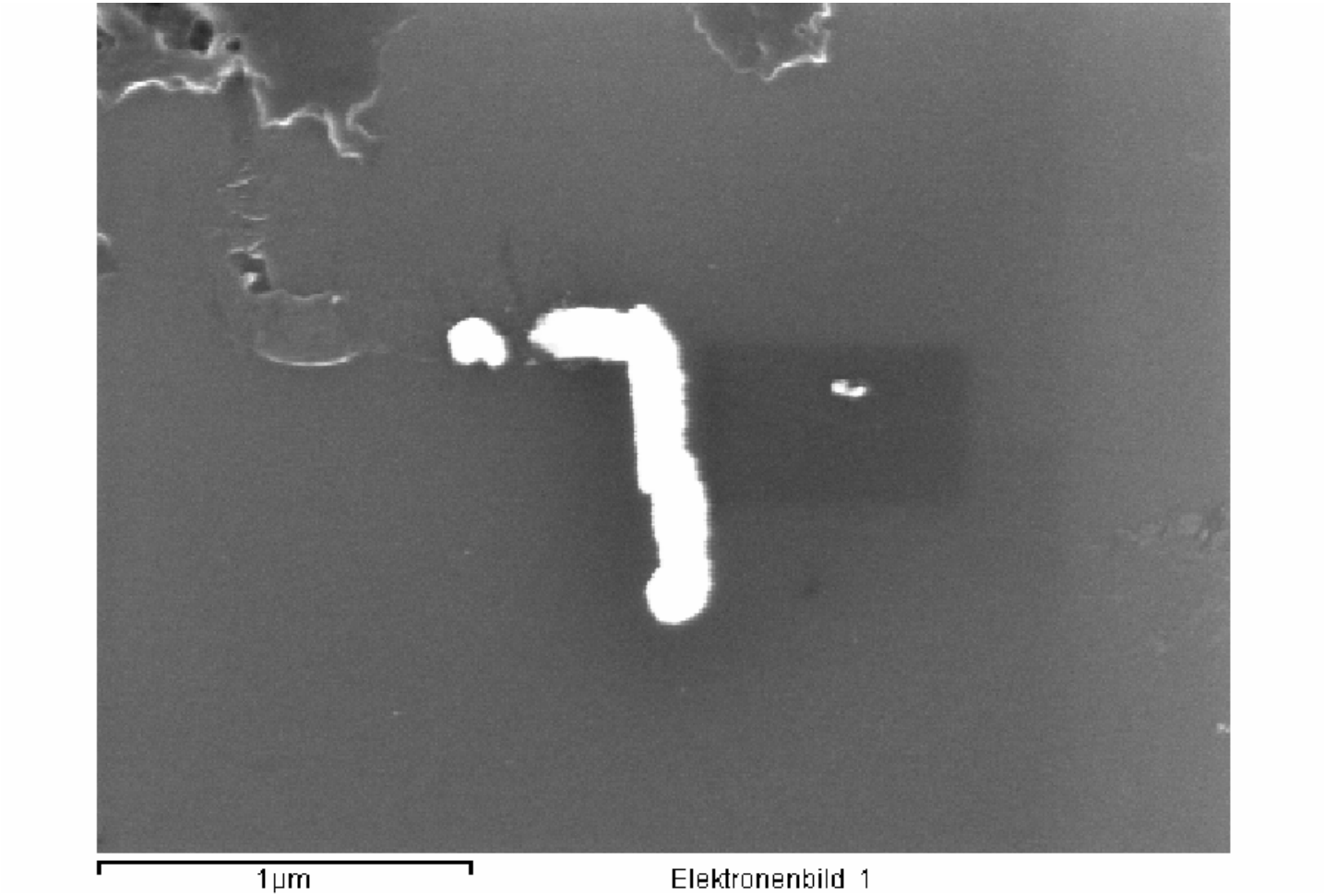


AFM images depicting the (a,c) height- and (b,d) phase images of DNA strands after the two-step metallization process: The upper part (a) and (b) shows an overview, below zoomed images (c) and (d) of a strand are depicted

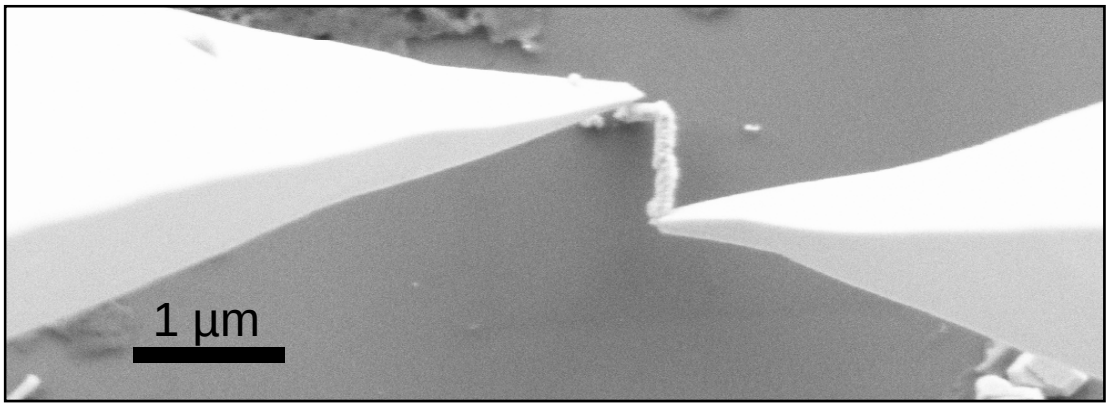
Fischler, Simon*, Nir, Eichen, Burley, Gierlich, Gramlich, Carell, *Small* **2007**

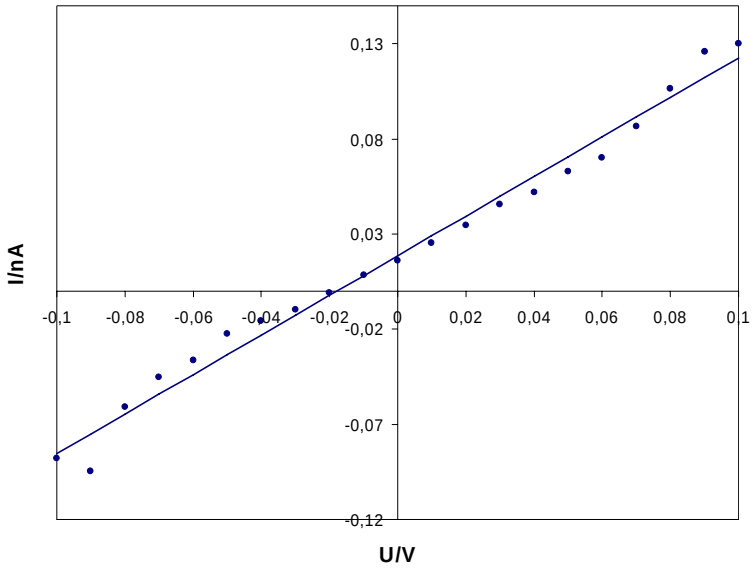
Metallised DNA

RWTH AACHEN UNIVERSITY



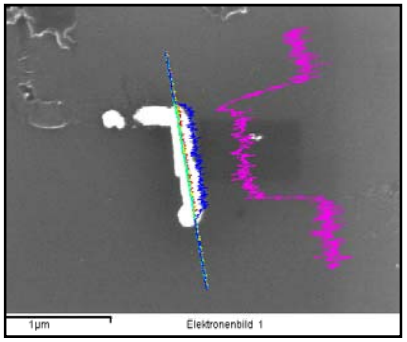
Preliminary results of electrical characterization

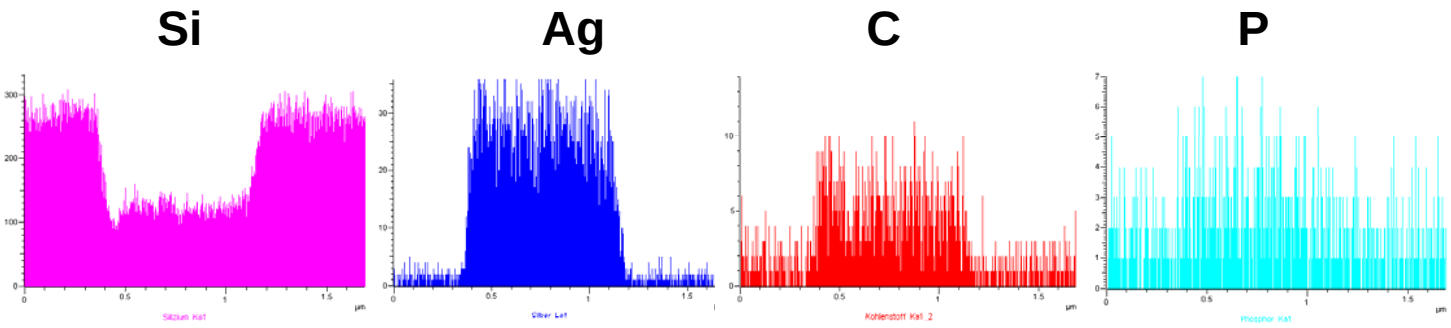




EDX analysis: elements detected along the line:

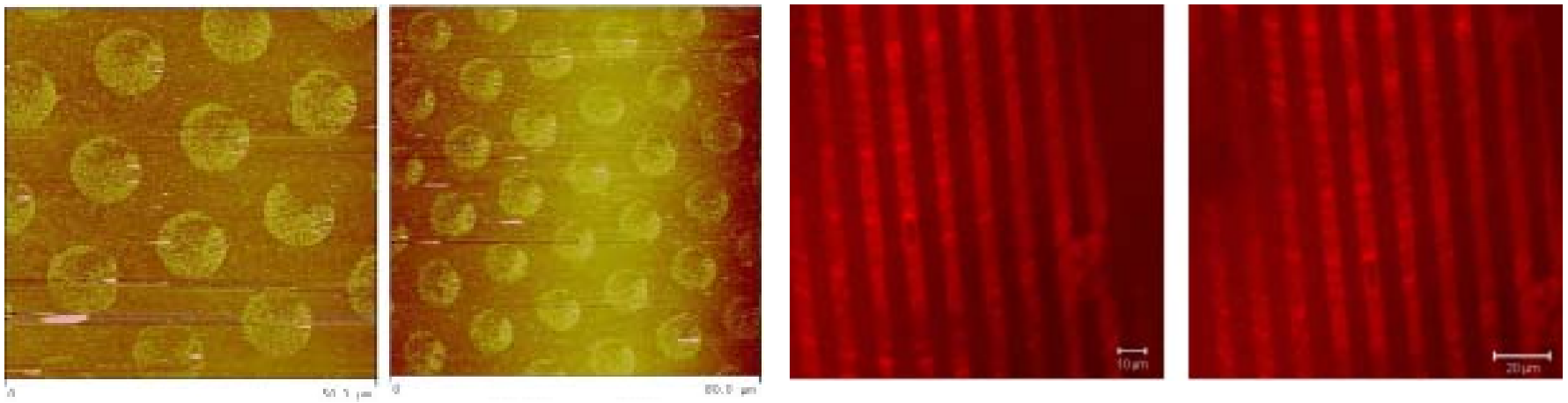
I(V)- curve (range -0.1 - +0,1 V)





Click with µ-contact printing

Printing 240406_S2A 5’-GCGCTGTXCATTCGCG



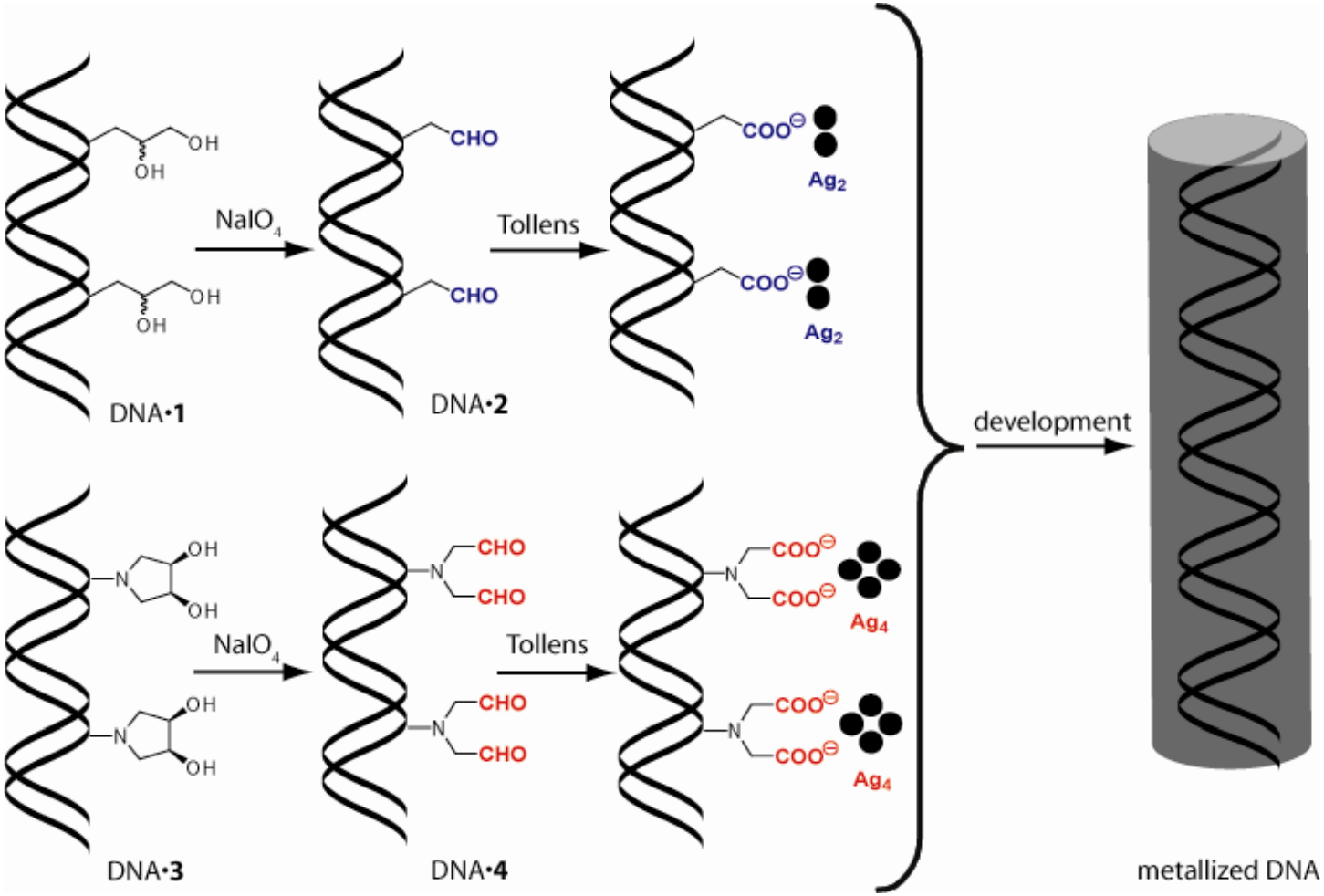
AFM picture

hybridized with
5’-Cy5-CGCGAAT at 2 °C

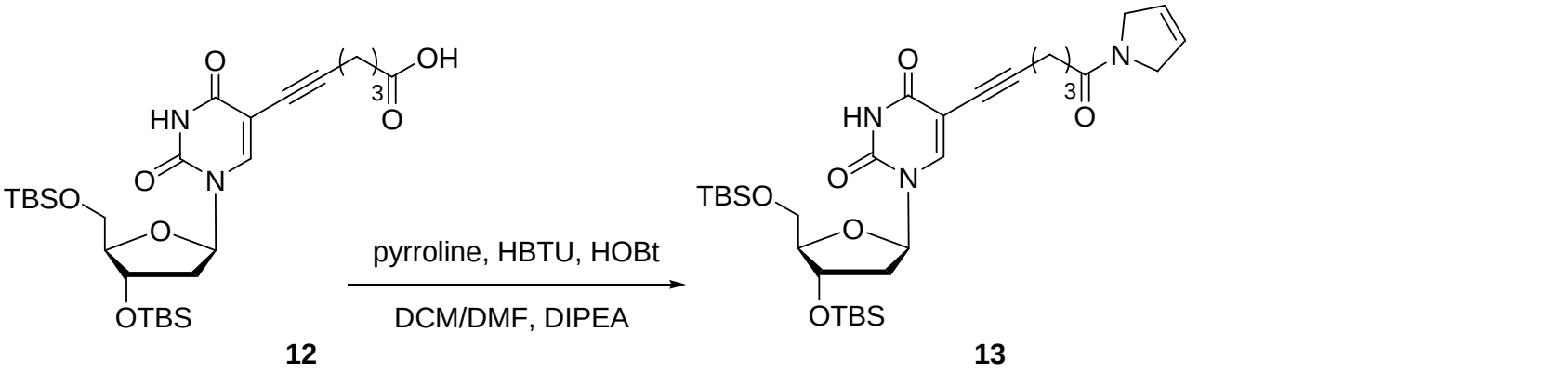
D. I. Rozkiewicz, J. Gierlich, G. A. Burley, K. Gutsmiedl, T. Carell, B. J. Ravoo, D. N. Reinhoudt
ChemBioChem **2007**, *8*, 1997-2002.

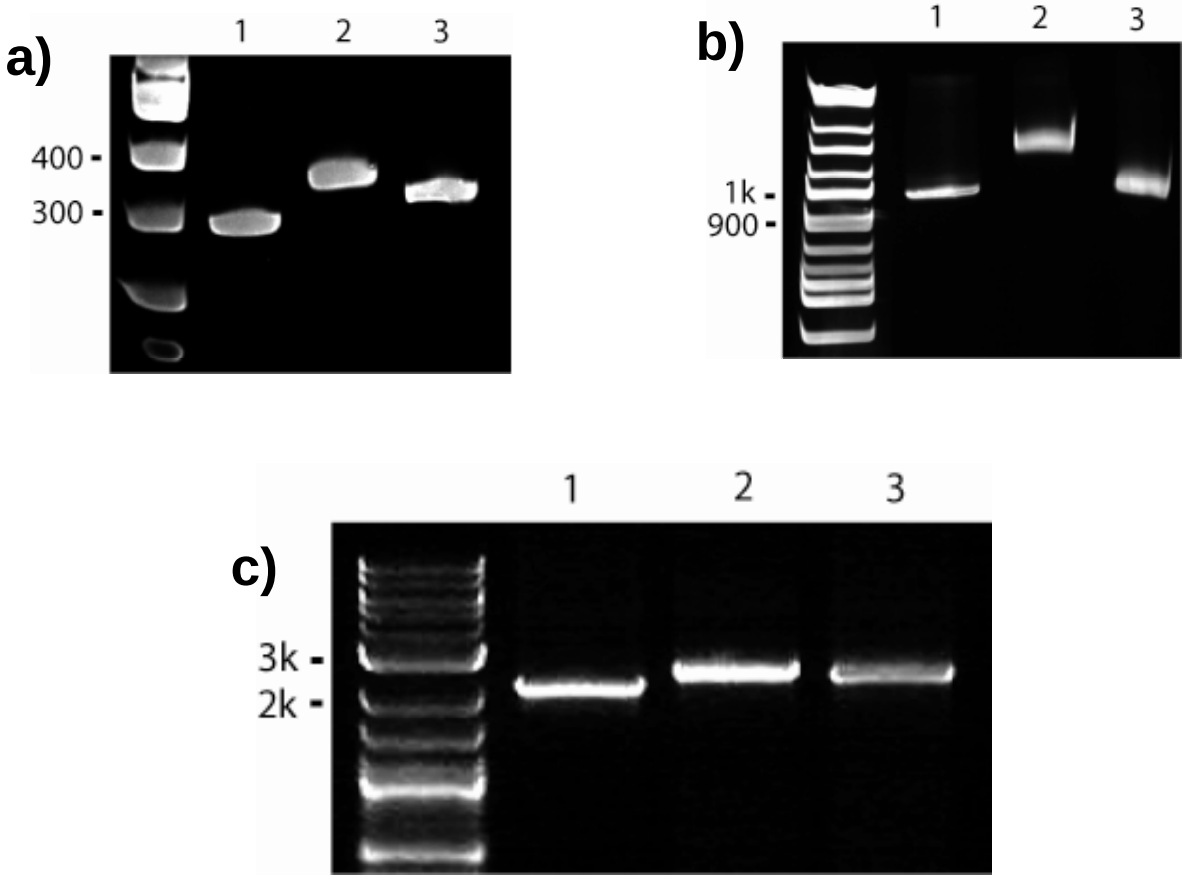
P. M. E. Gramlich, S. Warncke, J. Gierlich, T. Carell
Angew. Chem. Int. Ed. **2008**, *47*, 3442-3444.

Can we design the nucleus needed for metallization



Di-aldehyde modified DNA to generate a Ag_4 Cluster

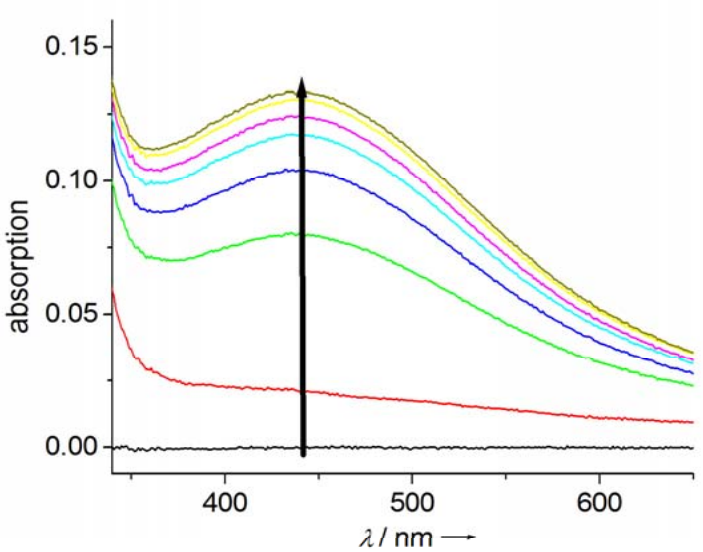




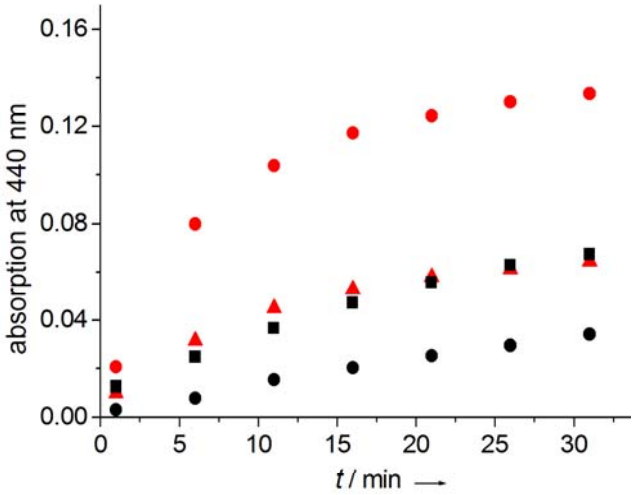
a) 300mer DNA. b) 900mer DNA. c) 2000mer DNA.

Lane **1**: **native** triphosphates: DNA•**N**;
Lane **2**: dTTP substituted with **monoaldehyde-**triphosphate
Lane **3**: dTTP substituted with **dialdehyde**-triphosphate

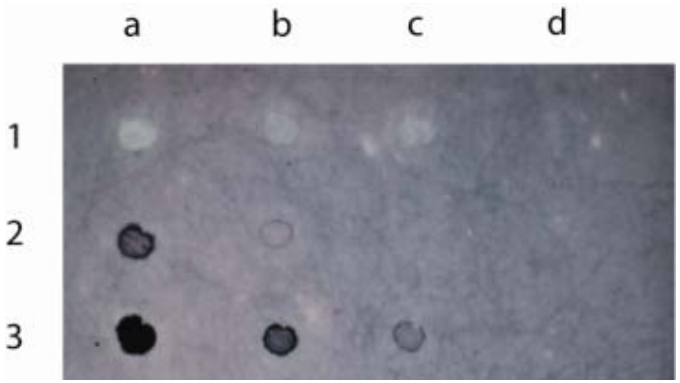
The Tollens reaction



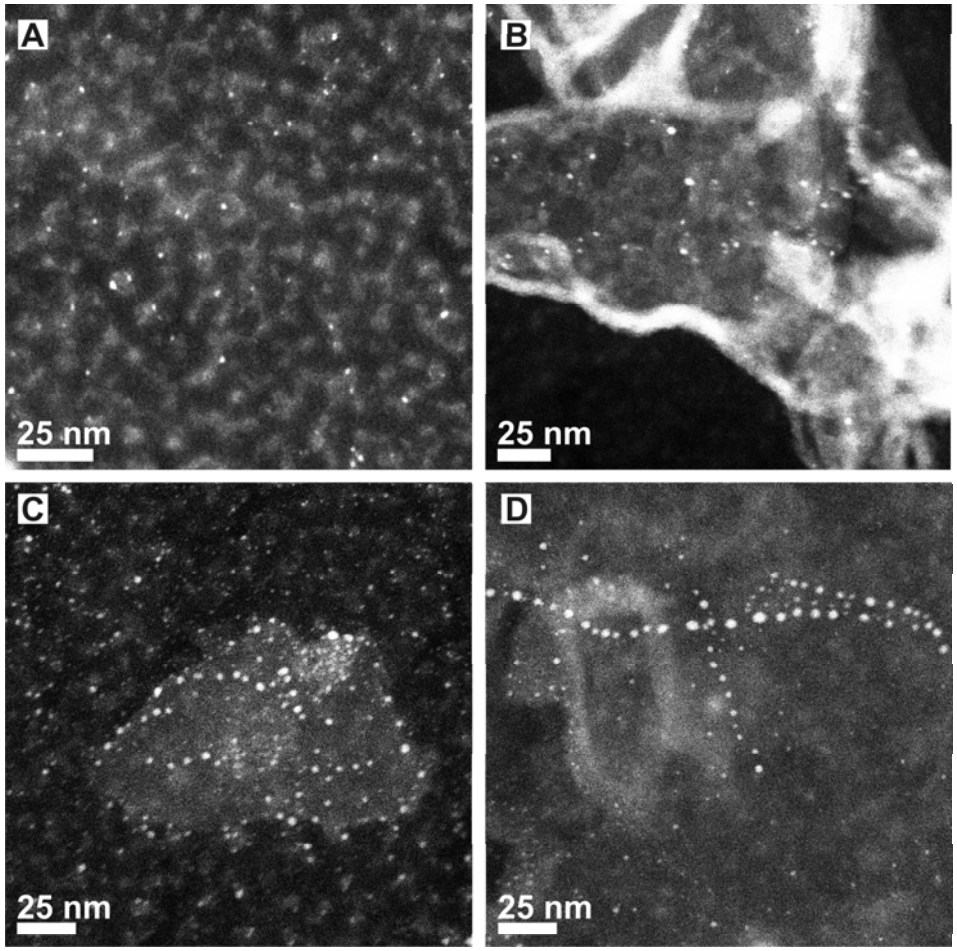
UV-VIS of the Tollens reaction
Black line: before addition of Tollens solution,
Colored lines: 5 min interval after Tollens addition



Plasmon peak development
Black: Monoaldehyde
Red: Dialdehyde

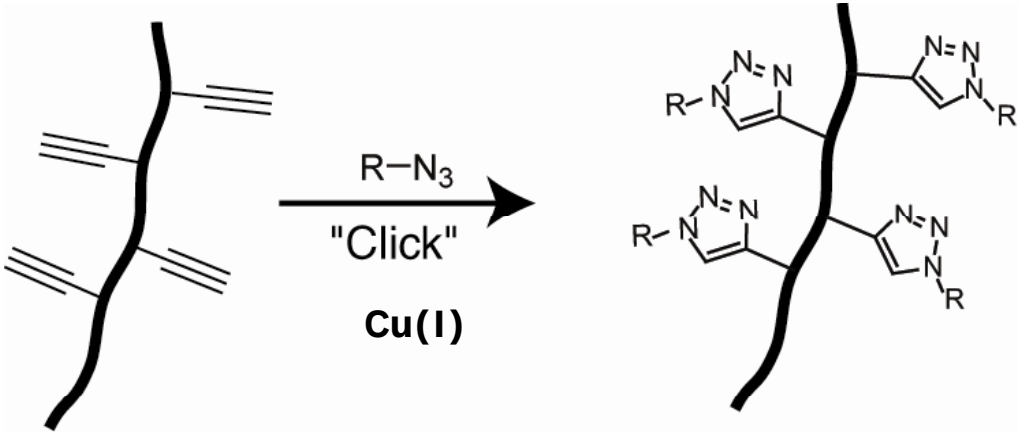


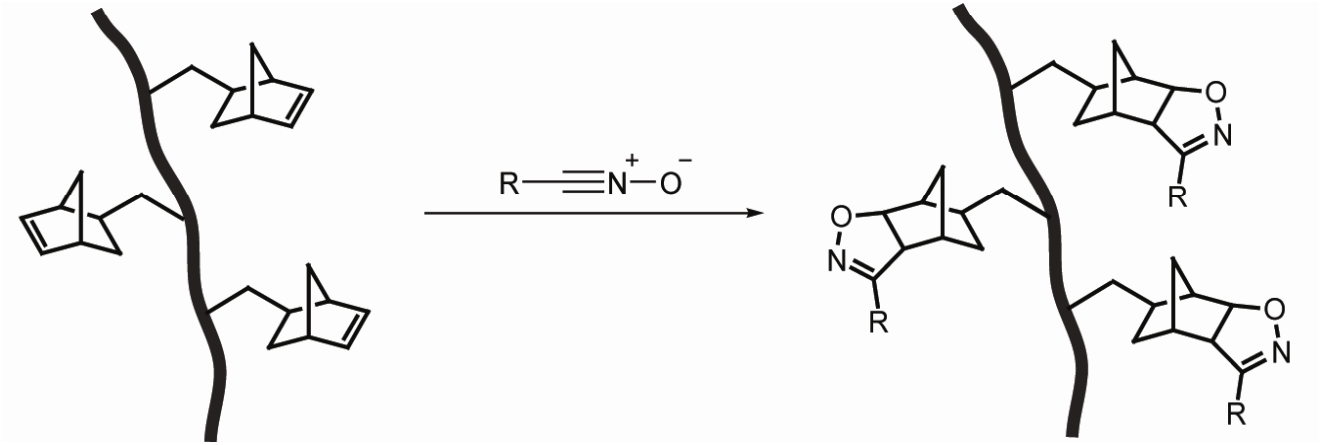
Membrane staining experiment performed with
1: Unmodified DNA
2: Monoaldehyde DNA
3: Dialdehyde DNA
a: 40 ng/µL, **b:** 4 ng/µL, **c:** 0.4 ng/µL, **d:** 0.04 ng/µL

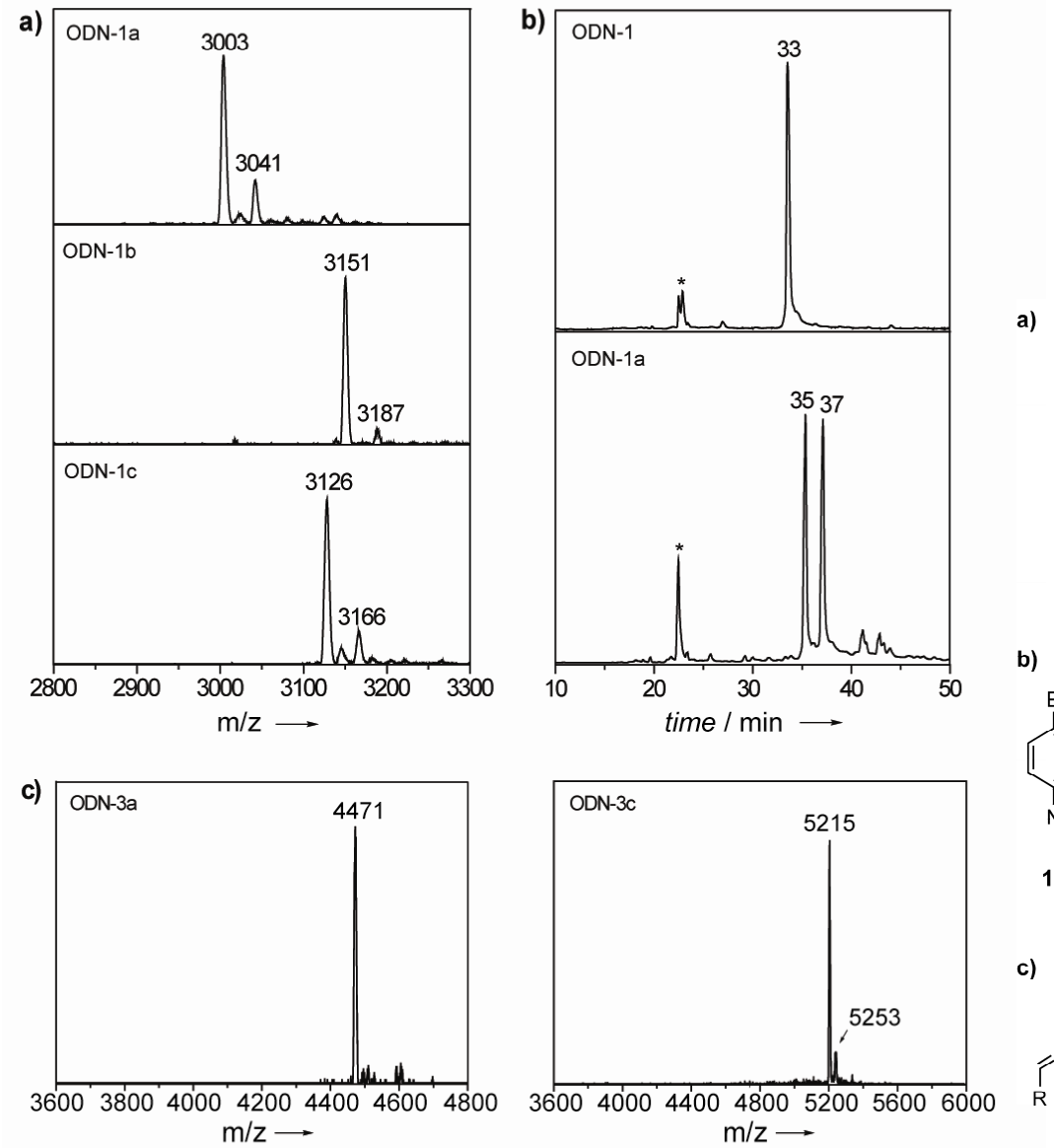


HR STEM micrographs.
A Tollens solution without DNA,
B Tollens solution incubated with native DNA,
C Tollens solution incubated with 900mer monoaldehyde-NA,
D Tollens solution incubated with 900mer dialdehyde-DNA.

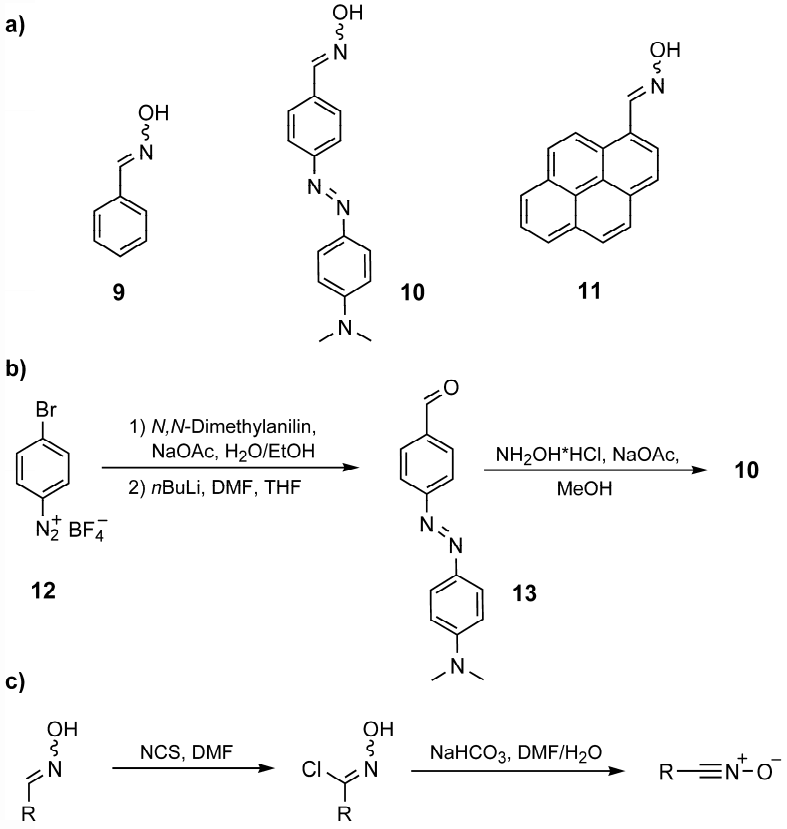
A new copper-free click reaction for DNA modification (strained alkenes plus nitrile oxides)







100% Efficiency
100 % Selectivity



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