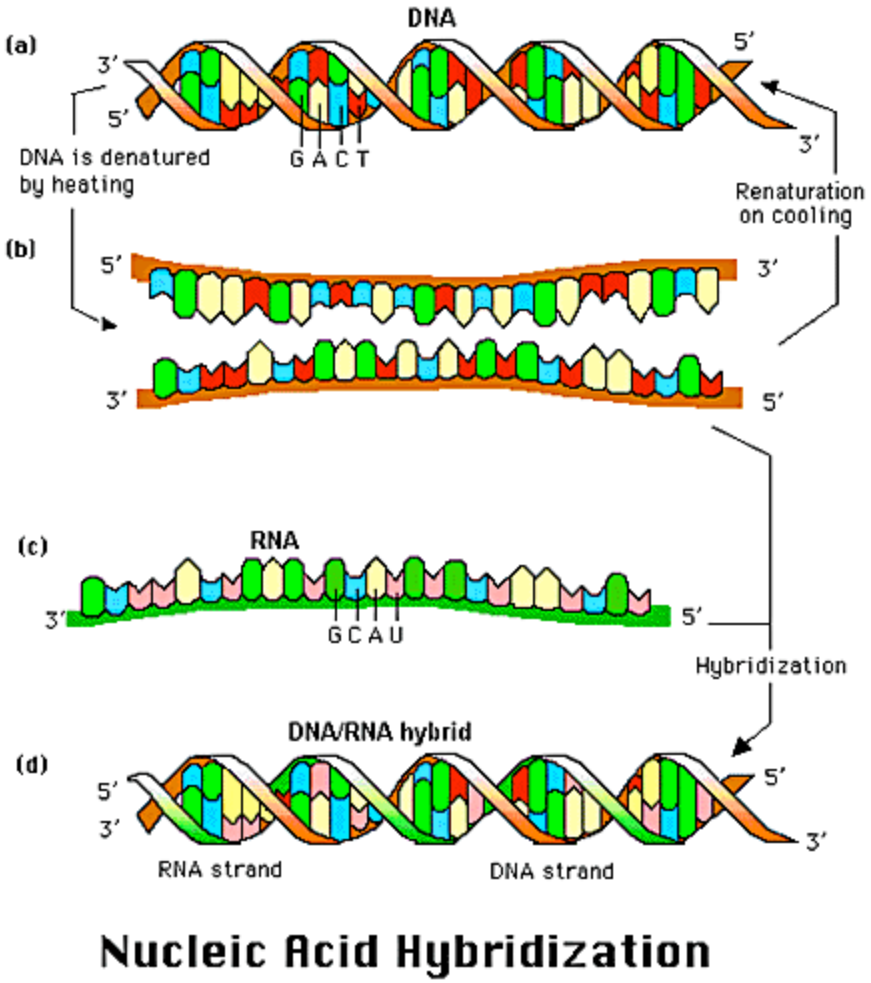
Ultra Scale High Density Hybrid DNA Memory

Mohamad Al-Sheikhly, William Bentley, Aris Christou, Joseph Silverman
Department of Materials Science and Department of Chemical Engineering

DNA Hybridization:The Basic Approach

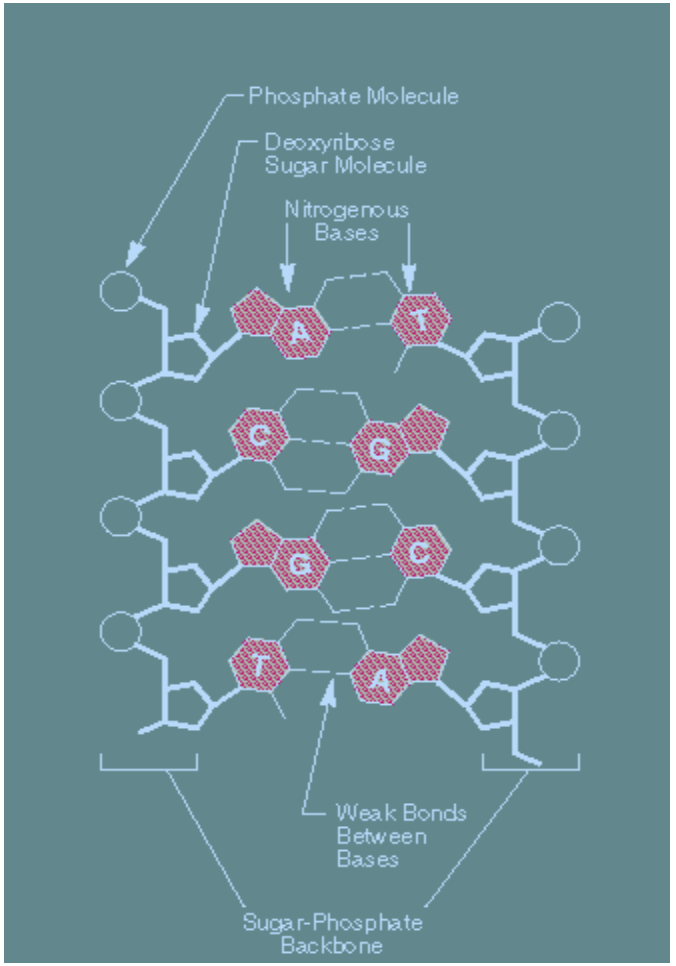


Nucleic Acid Hybridization

A DNA single strand can be hybridized to a complementary RNA chain , as well as, a complementary DNA single strand - the process which activates the observable fluorescing molecule

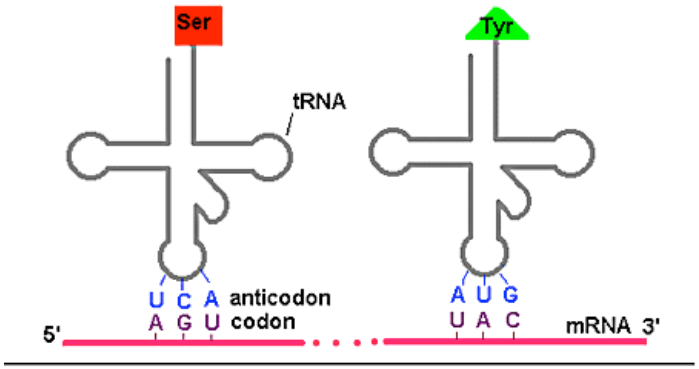
OUR APPROACH USES DNA HYBRIDIZATION

- DNA Hybridization is the hydrogen-bonding interaction between two DNA strands that obey Watson-Crick complementary rules.
- We induce this with infrared nanolasers



THE GENETIC CODE

DNA AS A DATA STORAGE DEVICE



2nd base in codon

1st base in codon	U	C	A	G	3rd base in codon
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	STOP	STOP	A
	Leu	Ser	STOP	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val	Ala	Glu	Gly	G

The Genetic Code

DNA stores the information necessary for the construction and maintenance of every living organism

RATIONALE FOR DEVELOPMENT OF A DNA MEMORY MODULE

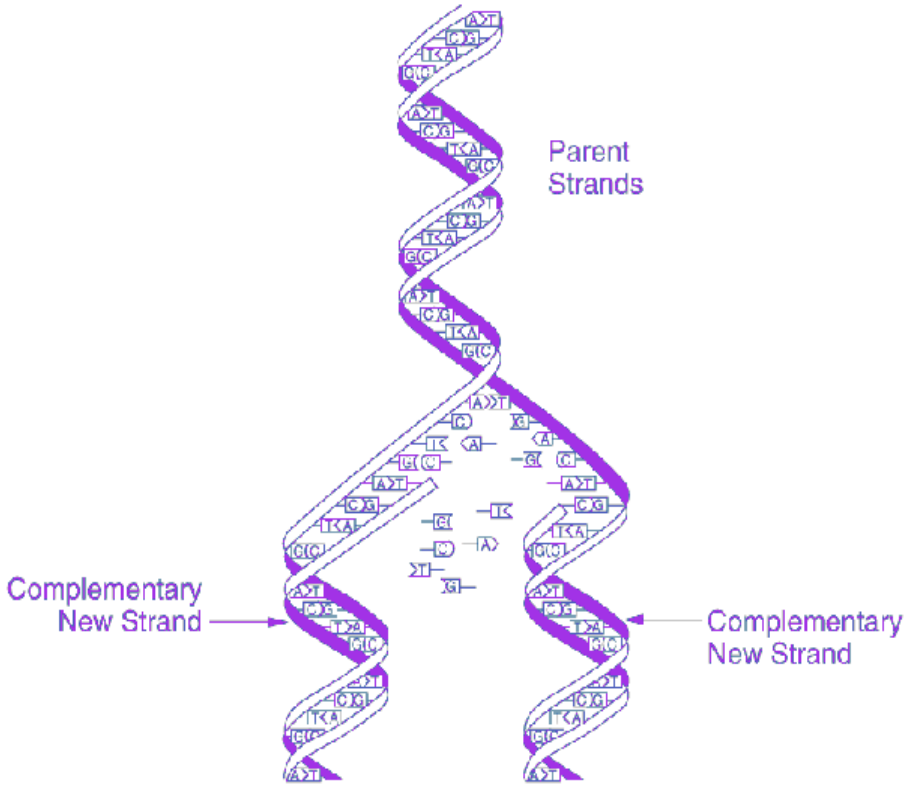
- What - Ultra-high density DNA memory module with massively parallel, near real-time data retrieving and storage
- What's New - DNA computers in liquid host have been demonstrated . We want a solid state nanoscale computer which may be self assembled on semiconductor surfaces.
- Utility - Massive memory, Pattern Recognition Achievable in nature:
  - A storage density ~ 1 bit per cubic nm (According to L. M. Adelman)

WHAT MUST BE DONE ?

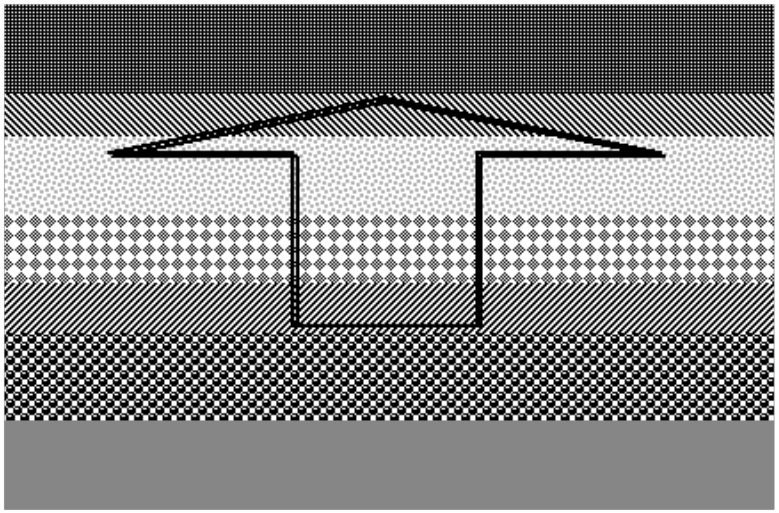
- Develop a DNA memory chip for hybrid systems by the following approaches:
  - A paradigm shift from enzymatic aqueous reactions to photo-induced surface reactions
  - Molecular Self Assembly of DNA on a Chip.
  - The use of advanced opto-electronics for data searching and retrieval
  - The adaptation of this approach into a practical, high density hybrid memory/rapid database-searching module

Enzymes and DNA: An Added Degree of Freedom For Data Storage

- Polymerase is an enzyme responsible for replicating a single strand of DNA.
- Ligase is an enzyme responsible for attaching to two single strands of DNA from end to end.



Schematic of a Hybrid DNA Memory Module Integrated with a Semiconductor Laser Array



Detector array (e.g. CCD array)

Beam condensor (Lenslet array)

Target DNA gel

Oligo probe array

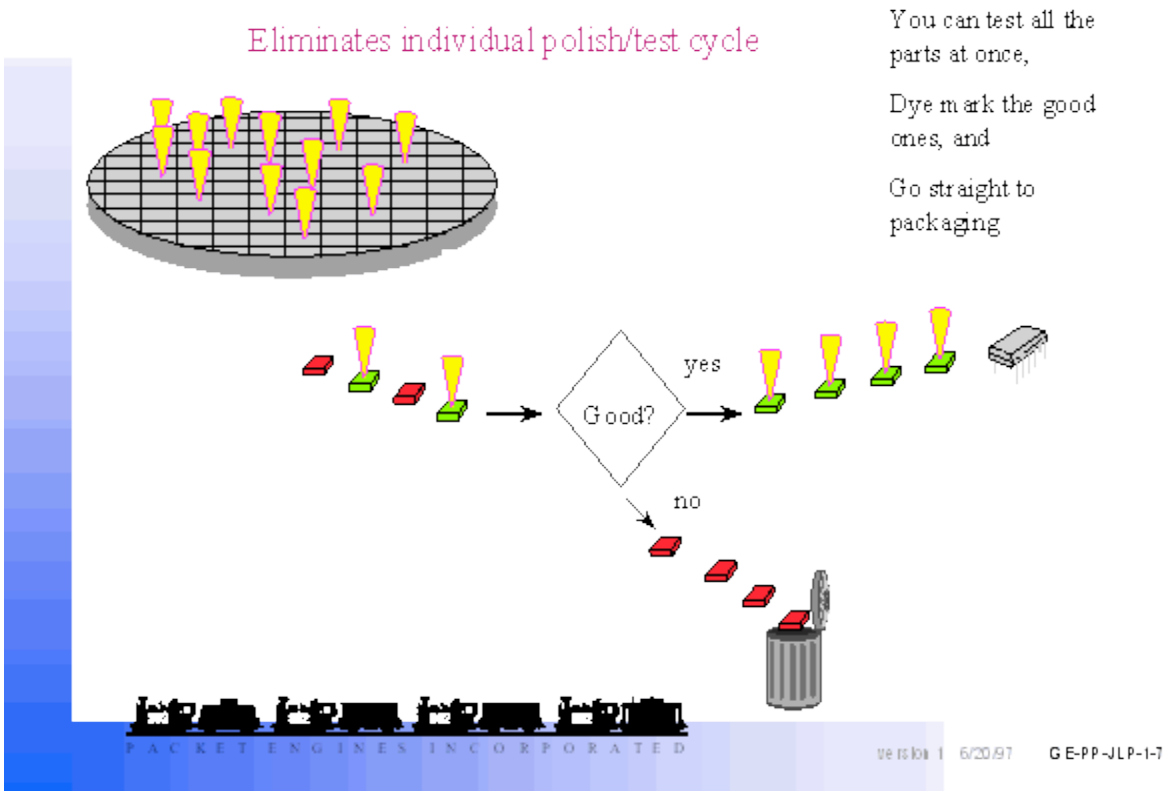
Beam conditioner (e.g., Lenslet array)

VCSEL array (e.g., GaN VCSEL array)

Substrate

VCSELS Covered With DNA on a Chip

Vertical-Cavity Surface Emitting Laser



Array of VCSEL With DNA on GaN/ GaAs Semiconductors

- 8 x 8 Array of individually addressed memory cells

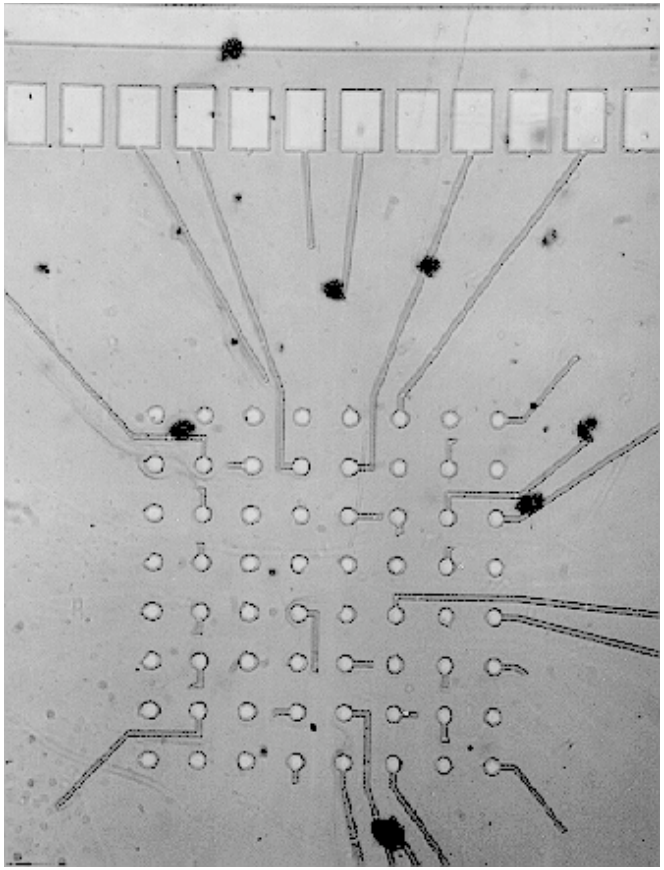
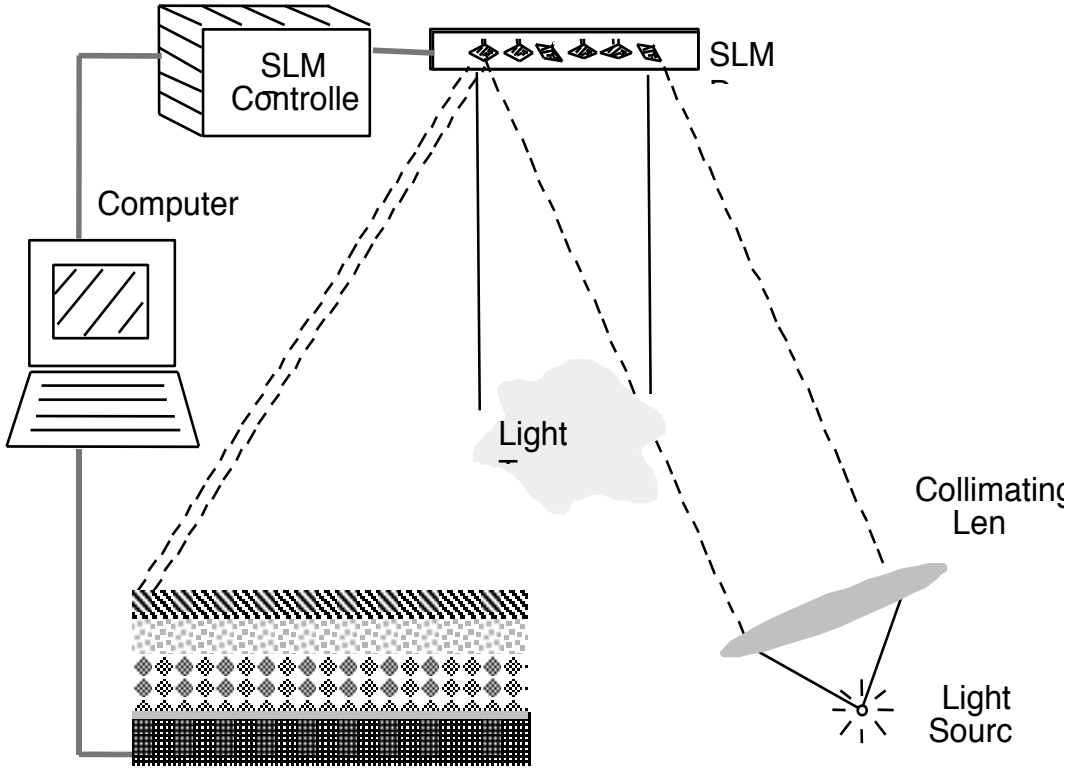


Photo-Induced Hybridization on a Chip with an External Source

THE TOOL: Spatial Light Modulation

1. Reflective type SLM
2. Transmissive type SLM

Reflective Type SLM



DNA memory system using a DMD spatial light modulator

Storage & Retrieval Operations for DNA Memory by Sequencing

Storage Operations

1. ASCII data string: *x* *y* *z*

2. Base-4 encoding: **AGCC TAGC TGAA**
(Virtual DNA strand)

3. Decomposition to 8-mers:

AGCCTAGC
GCCTAGCT
CCTAGCTG
CTAGCTGA
TAGCTGAA

In general, decomposition of an *n*-mer requires *n*-*k*+1 *k*-mers

4. Active the appropriate pixels with a laser or other means.

5. Data is now stored on the chip.

Retrieval Operations

1. Illuminate chip to activate the fluorescers.

2. Read the addresses of activated pixels with a CCD or other device. The following probes are identified (in order of increasing address):

ATCGACTT
CGGATCGA
GATCGACT
GGATCGAC
TCGGATCG

3. Sort and decompose by overlapping 7-mers and reconstruct the data complement

TCGGATCG
CGGATCGA
GGATCGAC
GATCGACT
ATCGACTT

TCGGATCGACTT

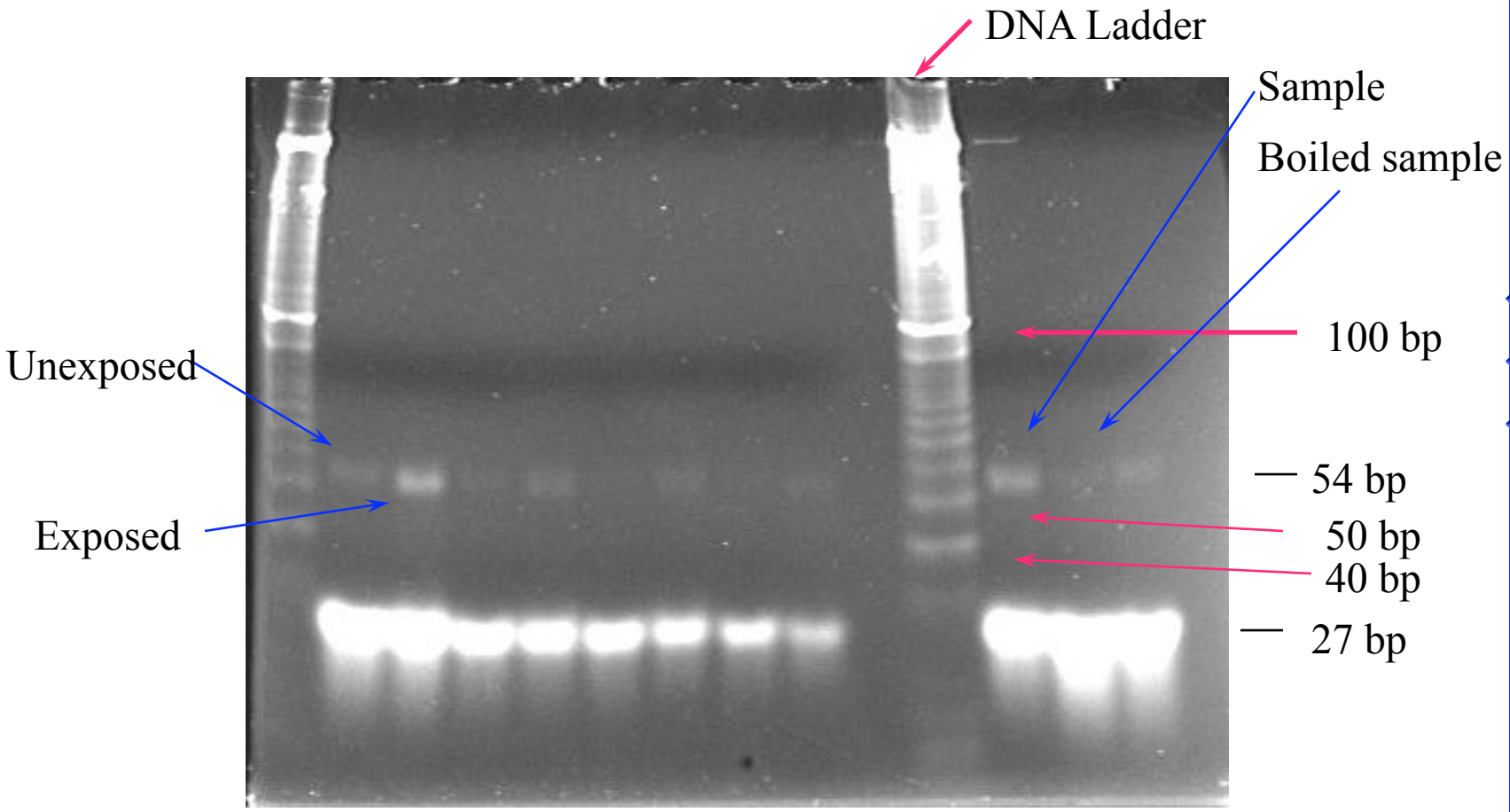
4. Take the complement:

AGCCTAGCTGAA

5. Decode ASCII data string:

x *y* *z*

Image of Hybridized DNA Strands Induced At 920nm



CONCLUSIONS

- Hybridization enhancement by photolysis demonstrated as required to validate DNA memory chip concept.
- Laser source practicality demonstration
- Variability of required effects as a function of wave length, exposure time and exposure rate shown
- Further work is needed to optimize design but concept for a DNA memory is viable.