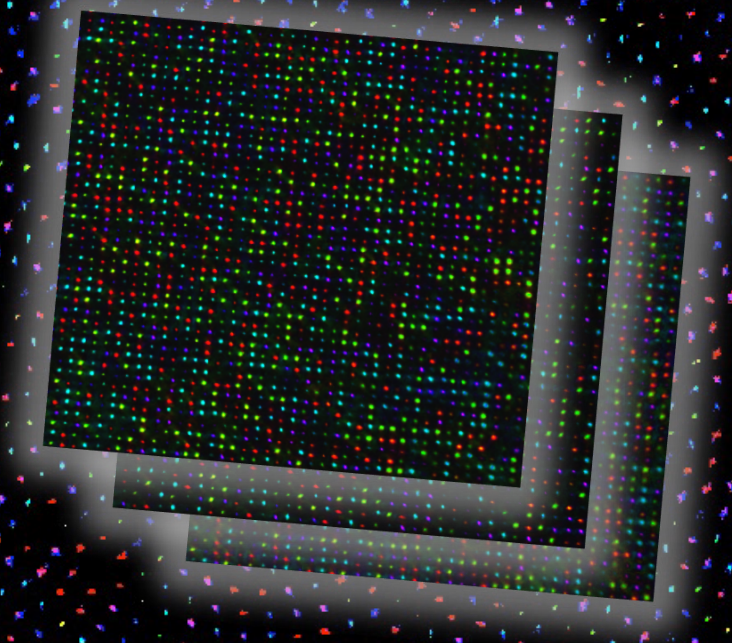
Laser nanostructuring in glass for long-term and large-scale digital preservation



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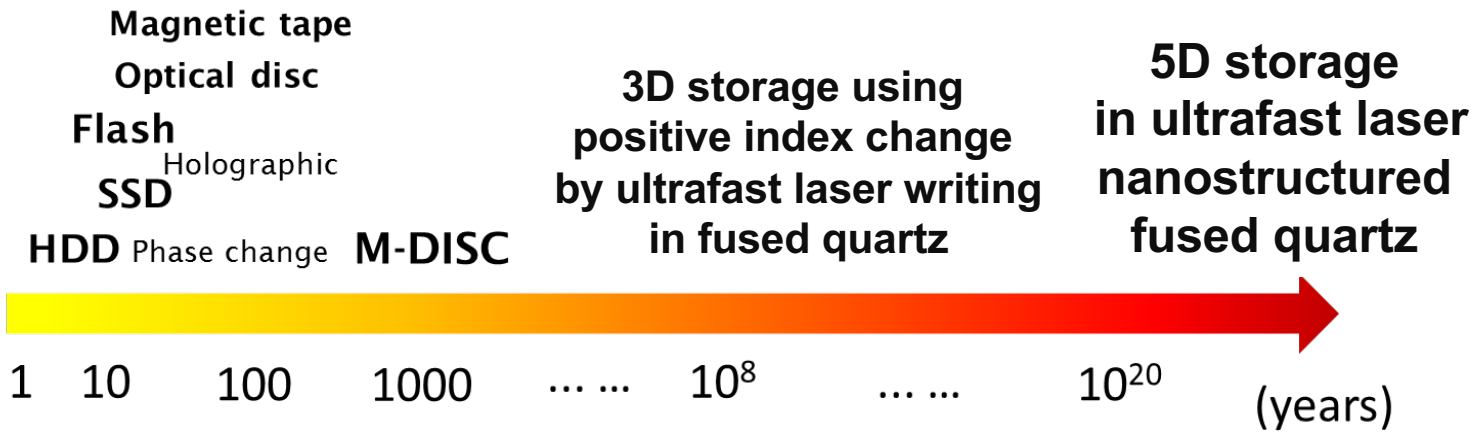
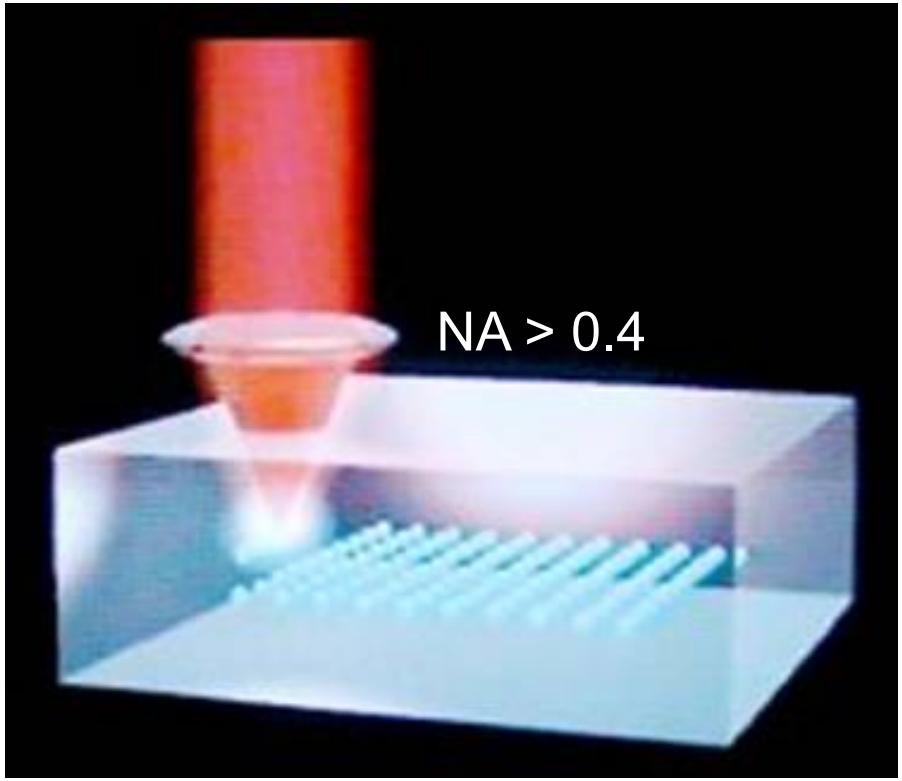
Long-term data preservation

- Nature's choice: DNA (1M years @ -18 ^{o}C)
- Current archiving technology: Magnetic tape (20 years)
- Optical based technologies: CD or DVD (10 years)
  M-Disc (1000 years)



Femtosecond laser direct writing: The principle

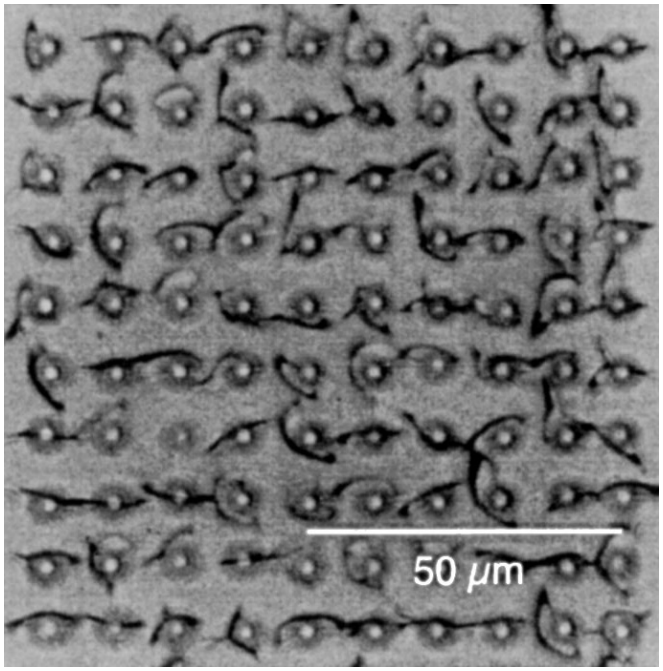
- Tight focusing of laser beam (e.g. λ =1030 nm, $\Delta\tau$ =300 fs) into transparent material
- High intensity leading to multi-photon absorption
- Structural changes in matter confined to focal volume due to short pulse duration – 3D



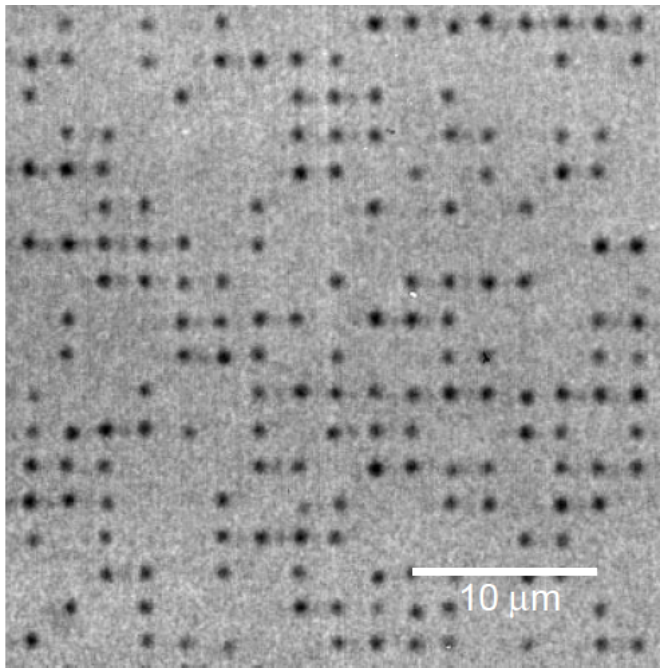
Intensity ~ 5×10^{13} W/cm^2
Electron temperature ~ 10^5 K /10 eV
Pressure ~ 10^6 bar

3D optical storage by femtosecond laser writing

Picosecond (10 x10^{-12} s) laser induces voids *with external stress*

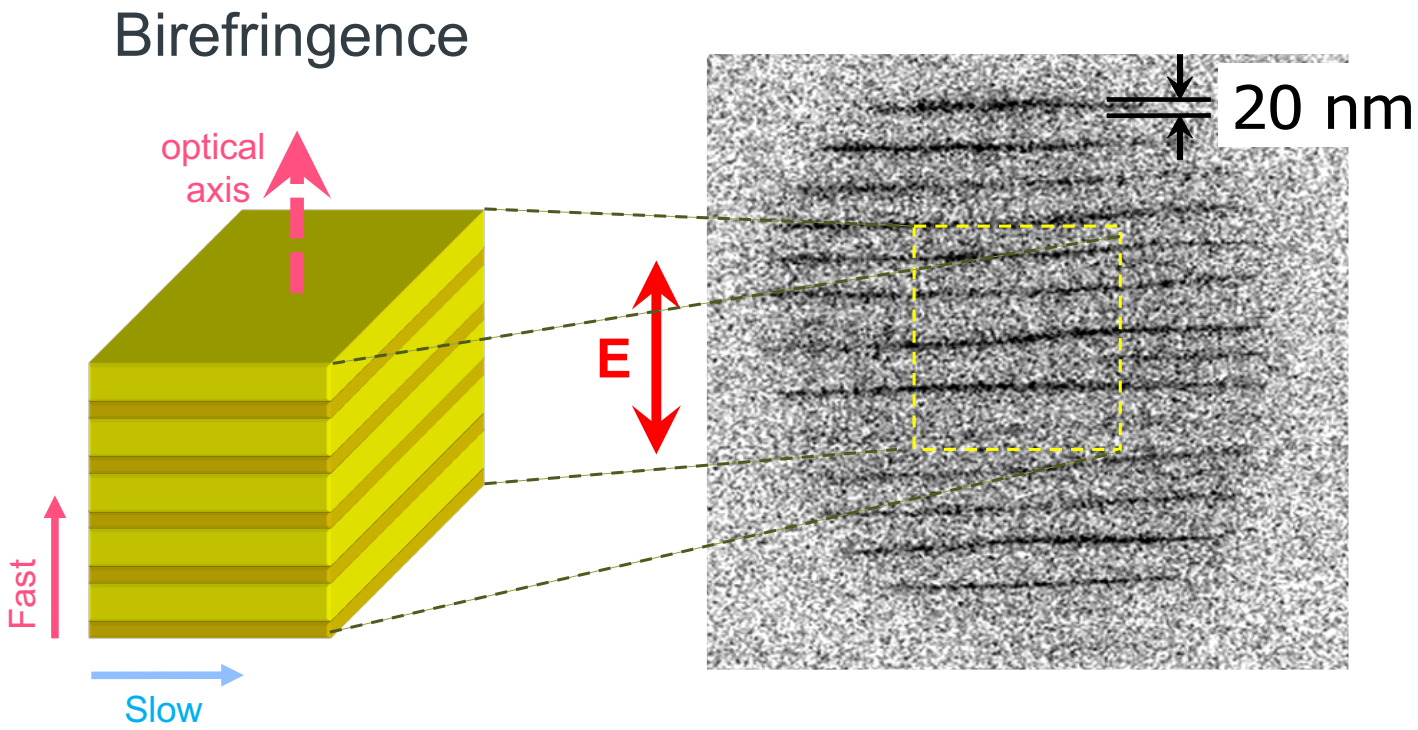


Femtosecond (100 x 10^{-15} s) laser induced *small* voids in quartz glass



Glezer et al.,*Optics Letters* (1996)

Ultrafast-laser nanostructured (ULN) quartz glass and self-assembled form birefringence



Femtosecond laser nanostructured glass:

$n_e - n_o = -5 \times 10^{-3}$

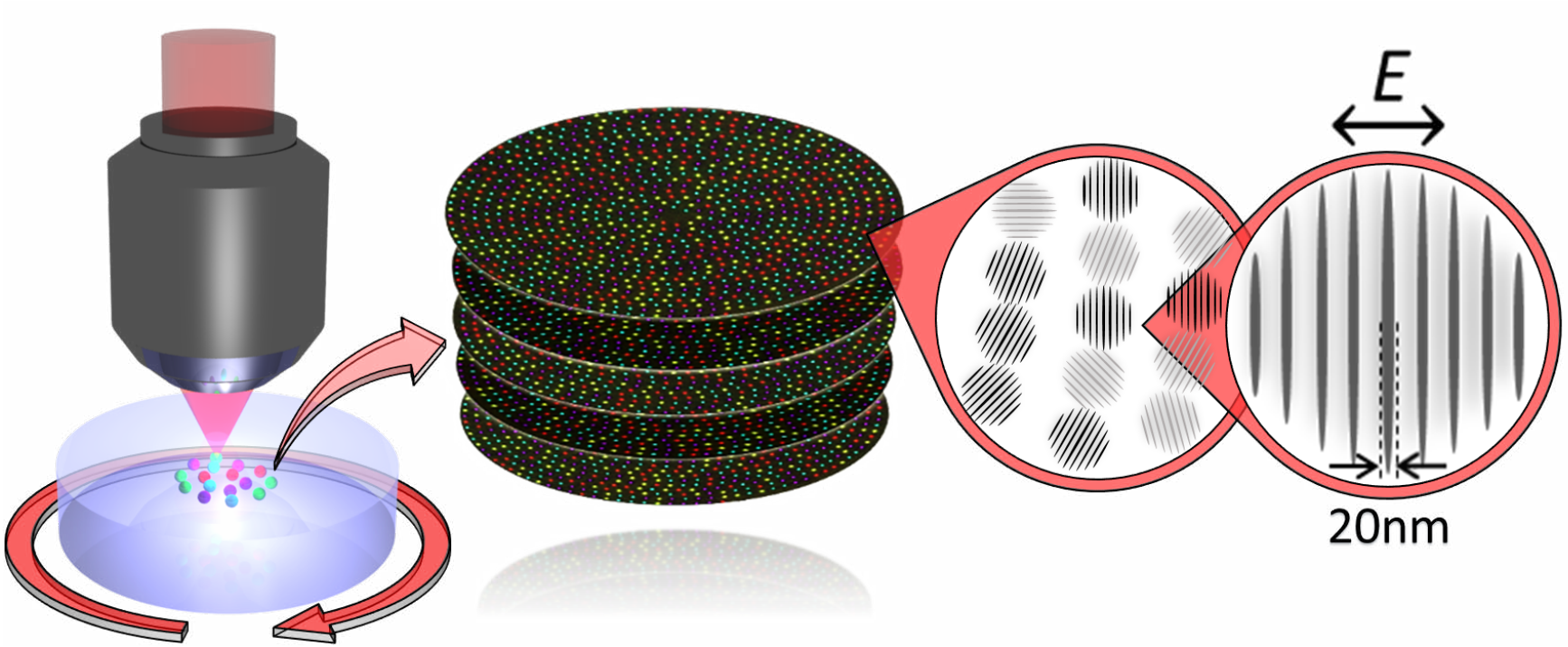
Quartz crystal:

$n_e - n_o = 9 \times 10^{-3}$

P.G. Kazansky et al., *Phys. Rev. Lett.*, **82**, 2199 (1999)

Y. Shimotsuma et al., *Phys. Rev. Lett.* **91,** 247405 (2003)

5D data storage
by ultrafast laser nanostructuring in glass



How it works?

- ✓ Position: 3 spatial dimensions
- ✓ Retardance = f(*Intensity, Number of pulses*)
- ✓ Slow axis = f(*Polarization*)
- ✓ Ultimate resolutions of slow axis angle ~5° and retardance ~5 nm.

1 Byte (8 bits) per spot:

32 states (5 bits) of slow axis orientation
8 states (3 bits) of retardance

Comparison

	CD	DVD	Blue-ray	5D
Capacity	0.7 GB	4.7 GB	23.5GB	360TB per disc
Last Long	5 years	7 years	7 years	10^20 years
Speed	150 kB/s (1x)	1.3 MB/s (1x)	4.5 MB/s (1x)	100 MB/s

Current writing speed: **3 KB/s**

Current capacity: **6 GB per layer**

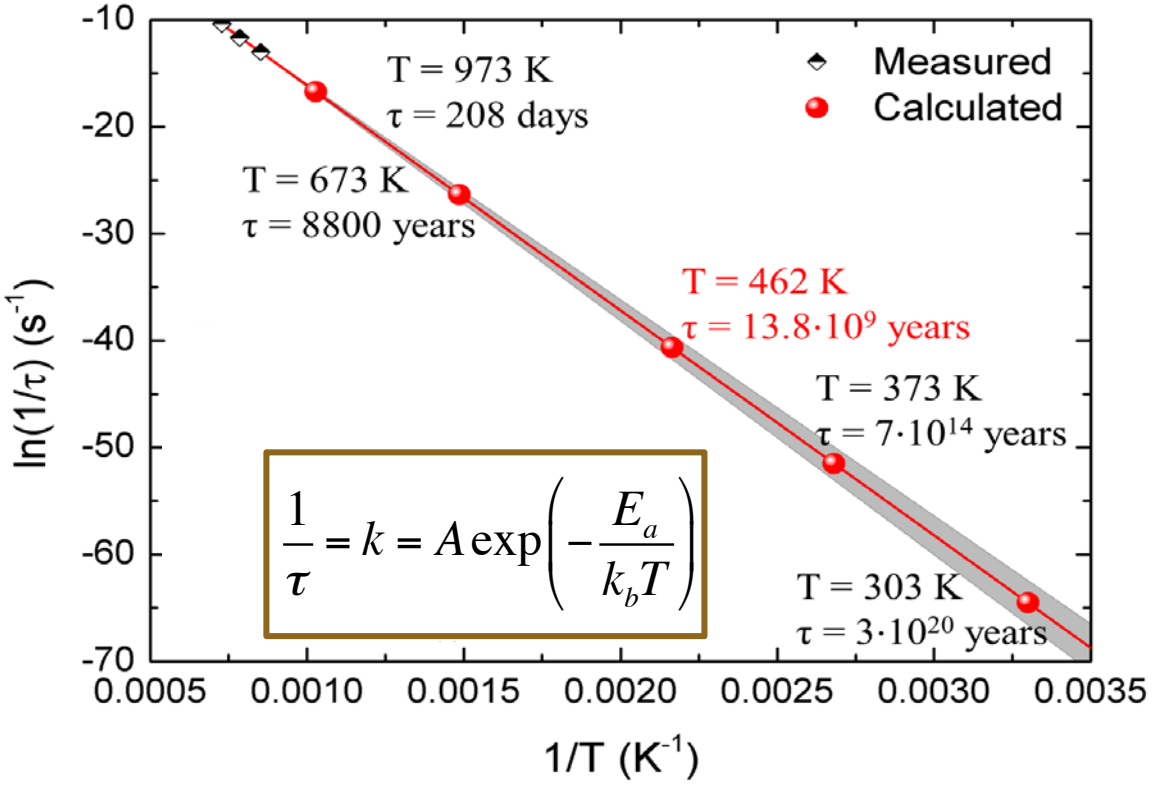
50 layers

280 GB/disc

Advantages of 5D: High capacity

Long lifetime

Thermal stability



$$R(t) = R_0 \times e^{-t/\tau}$$

T = 900° -> τ = 121 h

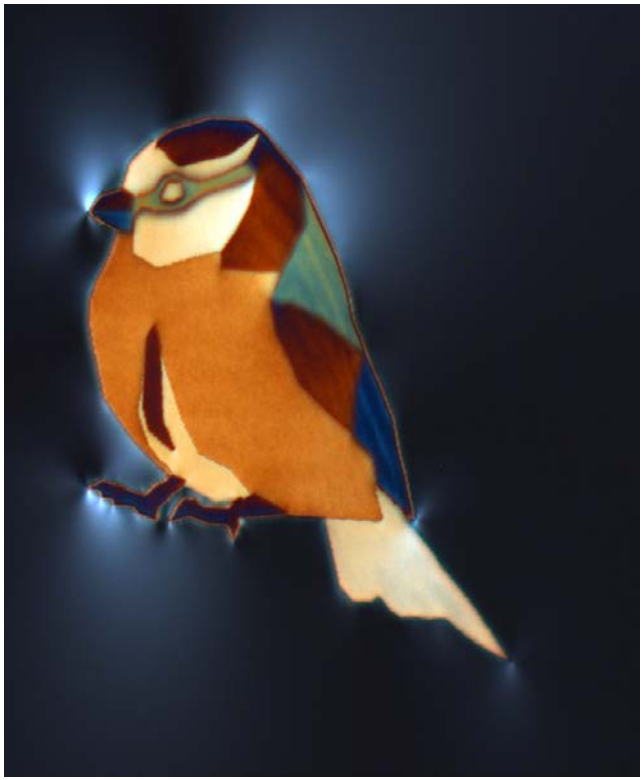
T = 1000° -> τ = 32 h

T = 1100° -> τ = 9 h

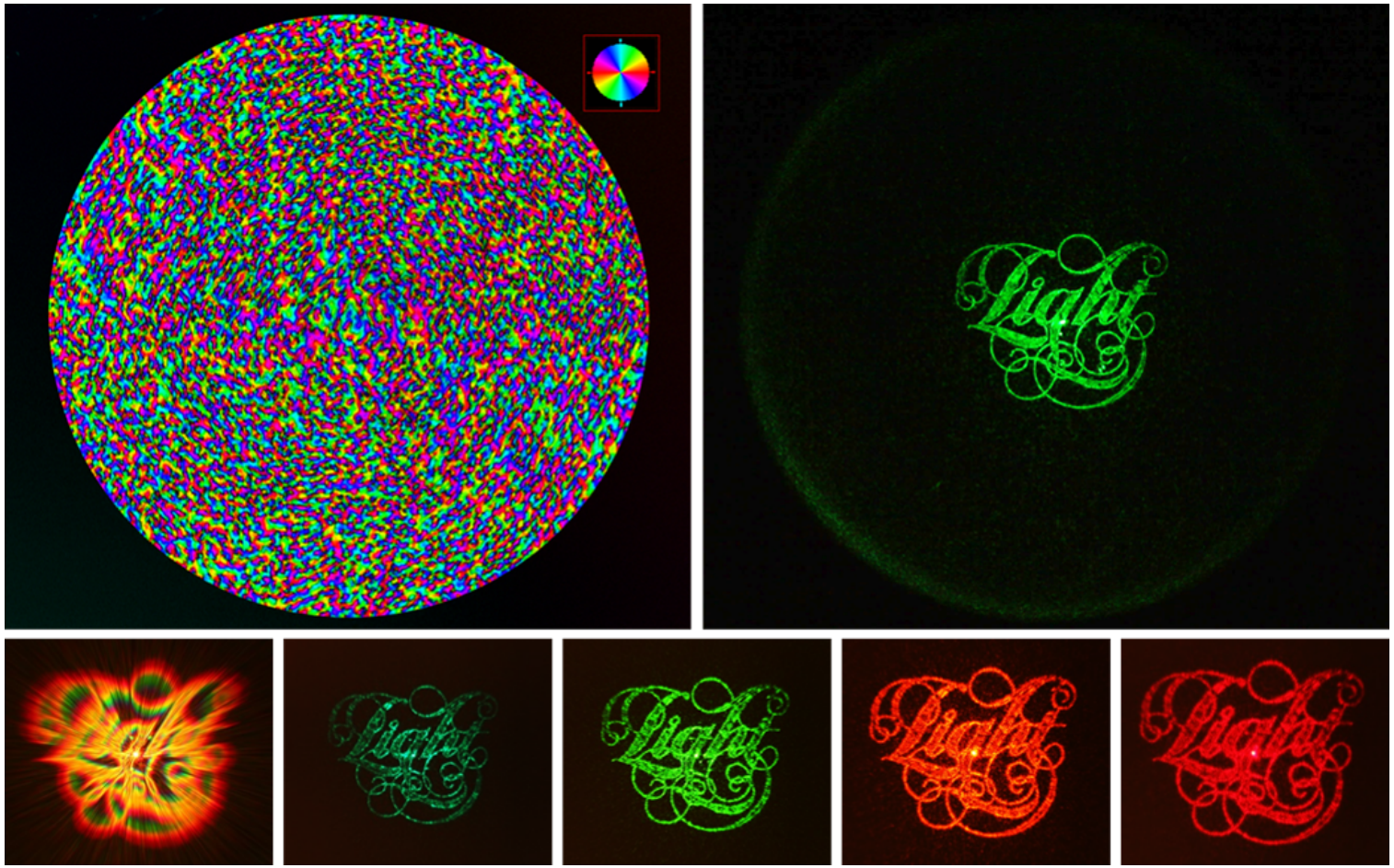
Using the Arrhenius law,
the lifetime can be extrapolated
to the room temperature

T = 30° -> $\tau = 300 \times 10^{18}$ years

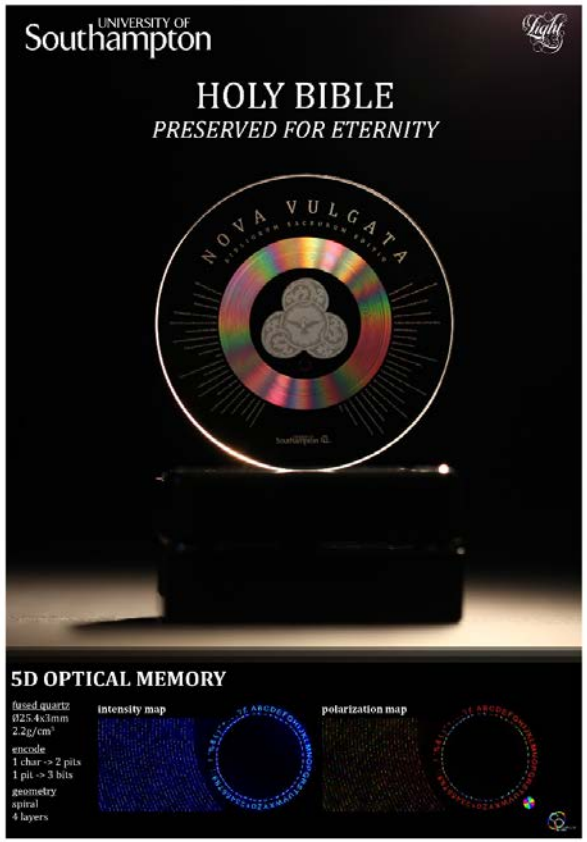
Bringing colours to life: Chameleon bird in glass



Geometrical phase hologram in glass



Eternal copy of Nova Vulgata presented to Vatican library



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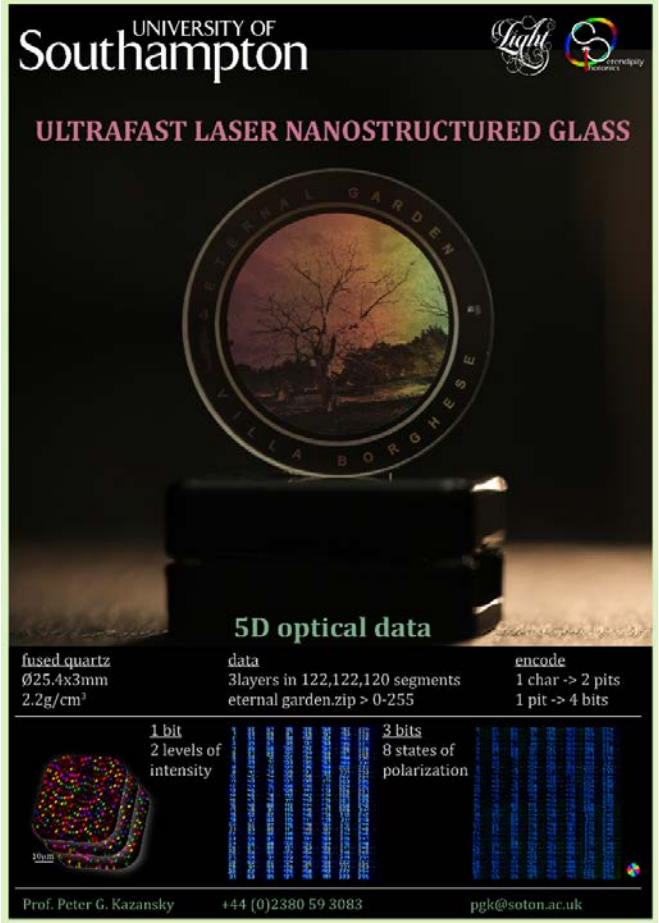
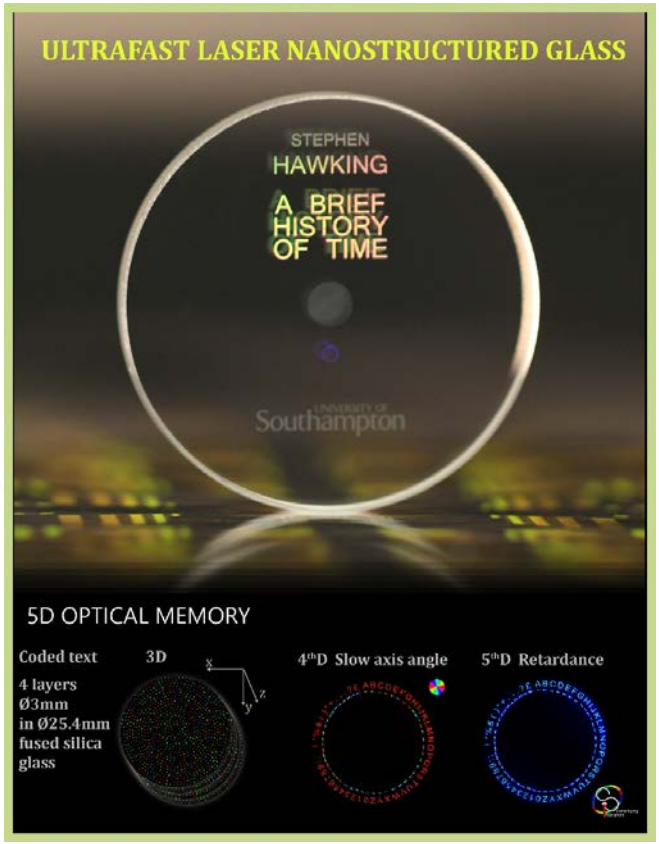
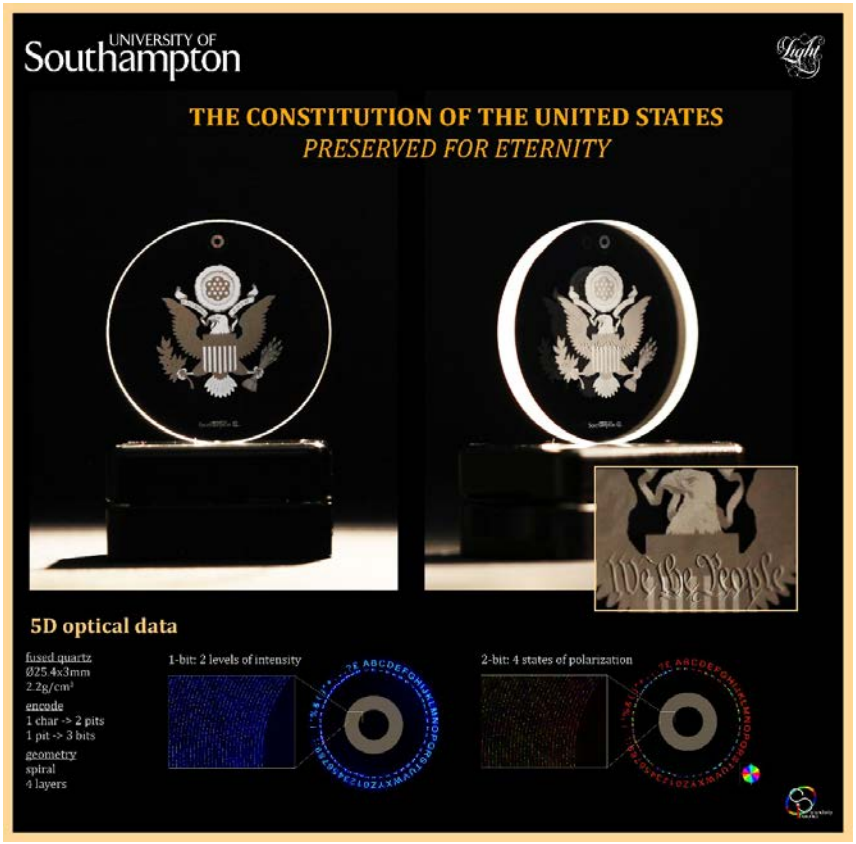


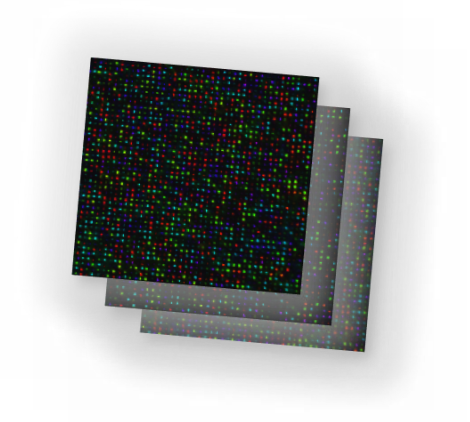
Eternal Documents





Conclusions

- Digital preservation with practically unlimited lifetime is possible by ultrafast laser nanostructuring in glass.
- Research towards increase of write and read speed is in progress.



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