Domain Manipulation with a light touch: Light assisted poling in ferroelectrics.

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4. All optical poling (AOP): Regular periodic arrays v. random self-organisation.
5. Latent poling:
6. Mechanisms and conclusions

1.Ferroelectrics (lithium niobate)

- Ferroelectrics properties:
  – Nonlinear (frequency conversion, QPM)
  – Piezoelectric (MEMS, electromechanical)
  – Electro-optic (modulators)
  – Photorefractive (storage, holography)
  – Acousto-optic (modulators)
  – Pyroelectric (detectors)

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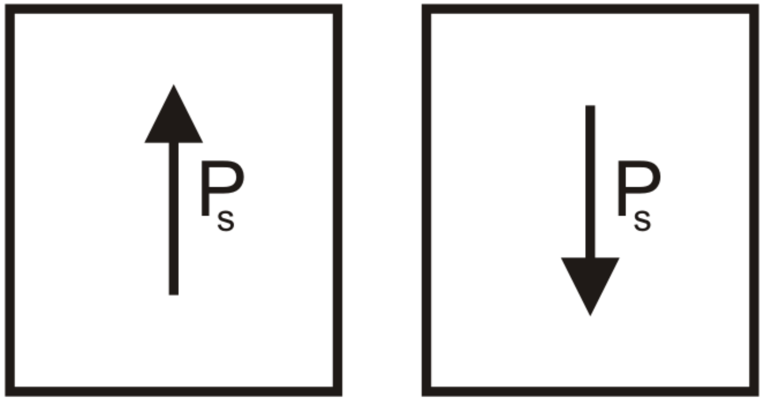
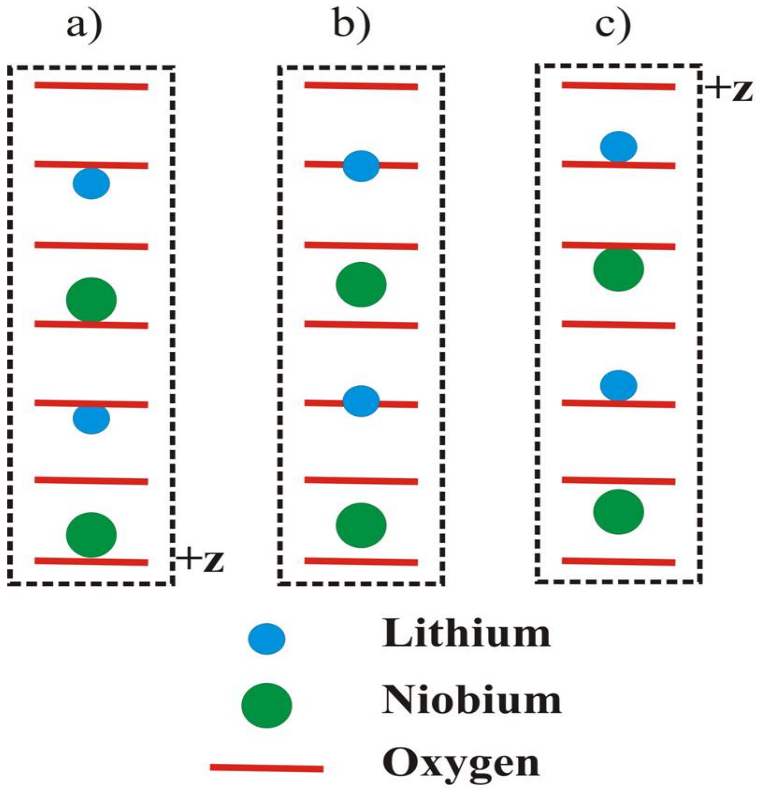
1. Ferroelectric materials and domains

- Ferroelectric crystals possess a spontaneous polarization, P_s
- Two stable "up" and "down" domains
- Second-order nonlinear susceptibility, $\chi^{(2)}$, has sign reversal needed for QPM



1. Ferroelectrics and domains

- Domain structure is important, and *can be engineered*: Lithium niobate



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1.Tensor properties

- All properties are governed by domain orientation (+z c.f. –z)
- The sign of all coefficients is reversed, hence:
  - QPM devices.
  - Electro-optic switching (induced $\pm \Delta n$)

$$\Delta n = -\tfrac{1}{2}\, r\, E\, n^3 \quad (+r \text{ or } -r)$$

  - Cancellation of photorefaction..

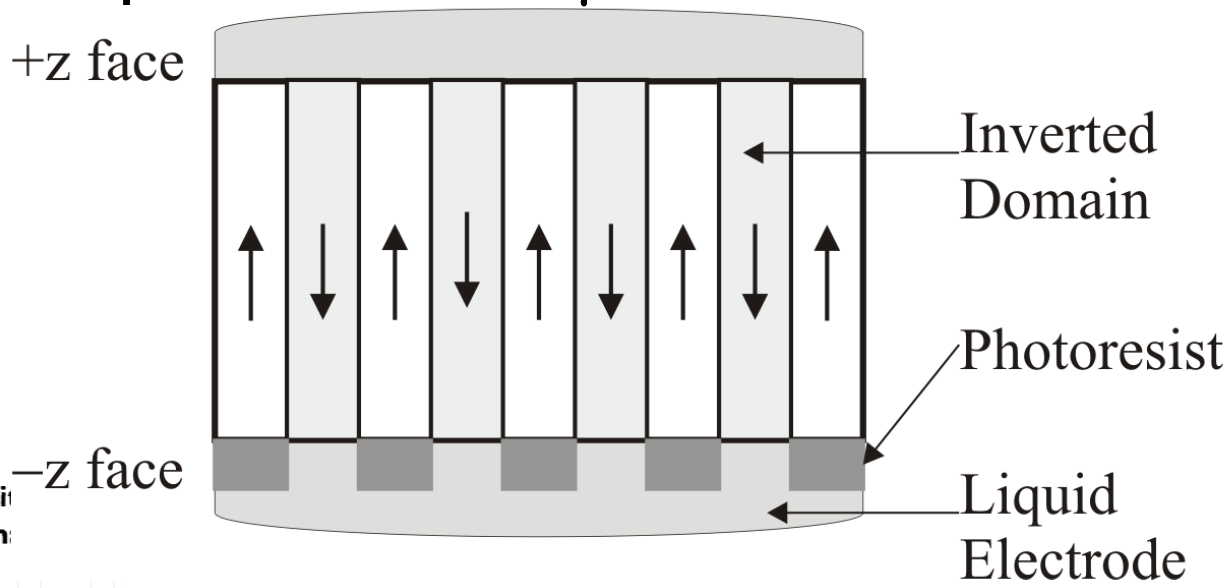
1. Spatial domain patterning

- Need controllable technique for domain patterning over large areas (cm squared)

  that is:
  - Easy
  - Fast
  - Can make small sizes (< 1μm)
  - Of variable depth (but at least waveguide dimension)

2. E-field Domain Inversion

- Domains switched by E-field
  - Coercive field, E_c ~ 22 kV mm^{-1}
- Form QPM grating: PPLN
- Typical periods: 4-18 μm



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2. Alternative domain inversion techniques

- E-beam irradiation: charging a problem.
- Ion beam, focussed ion beam: expensive.
- AFM: small areas only (100µm squared: stitching needed).
- Try using photons?

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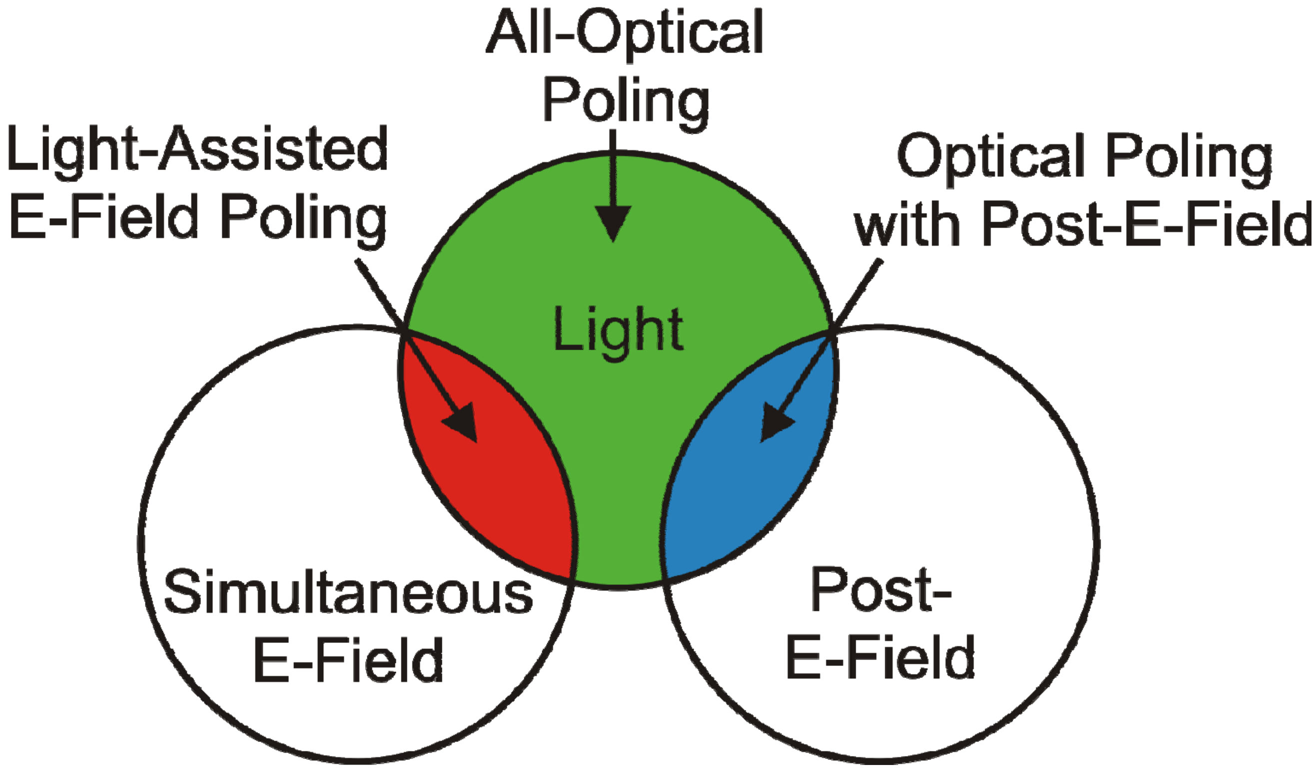
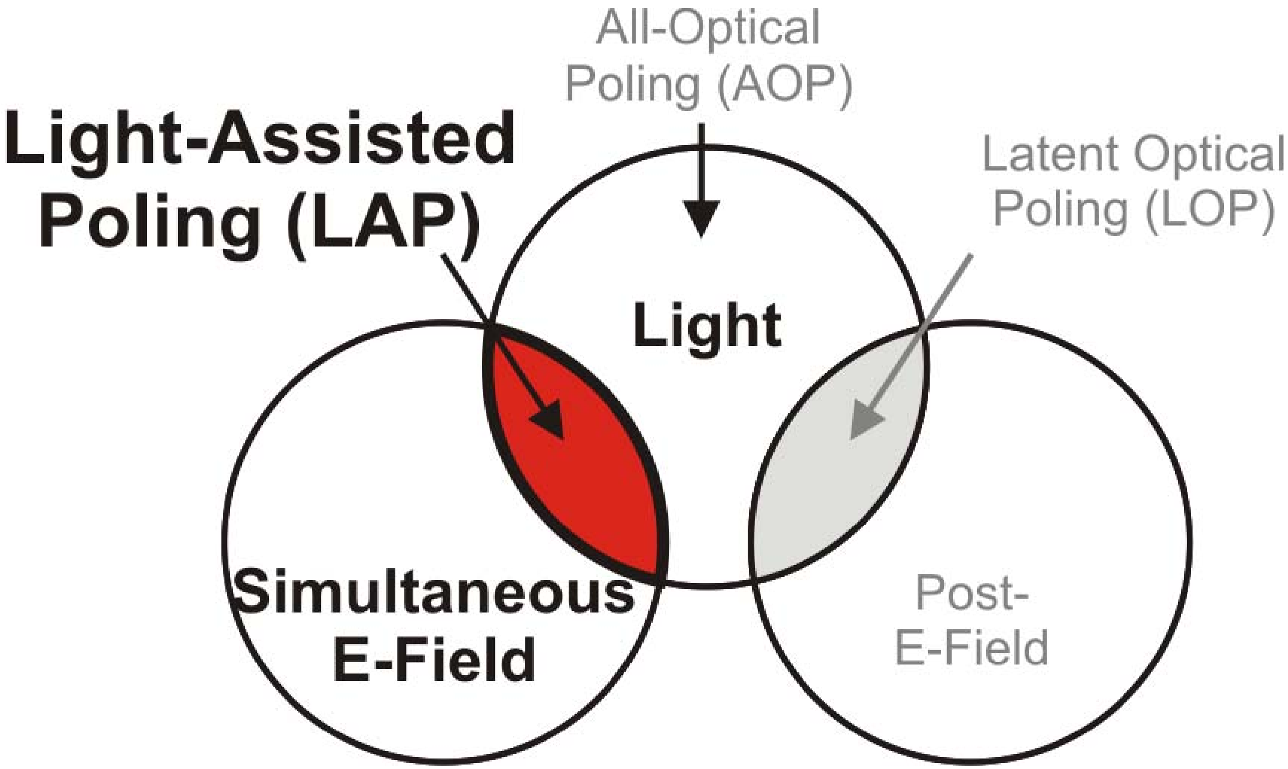
3. Optical poling techniques

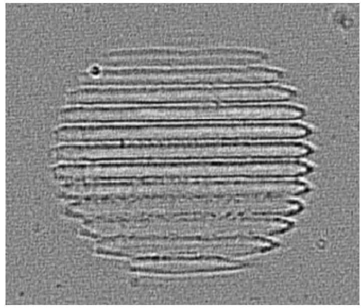


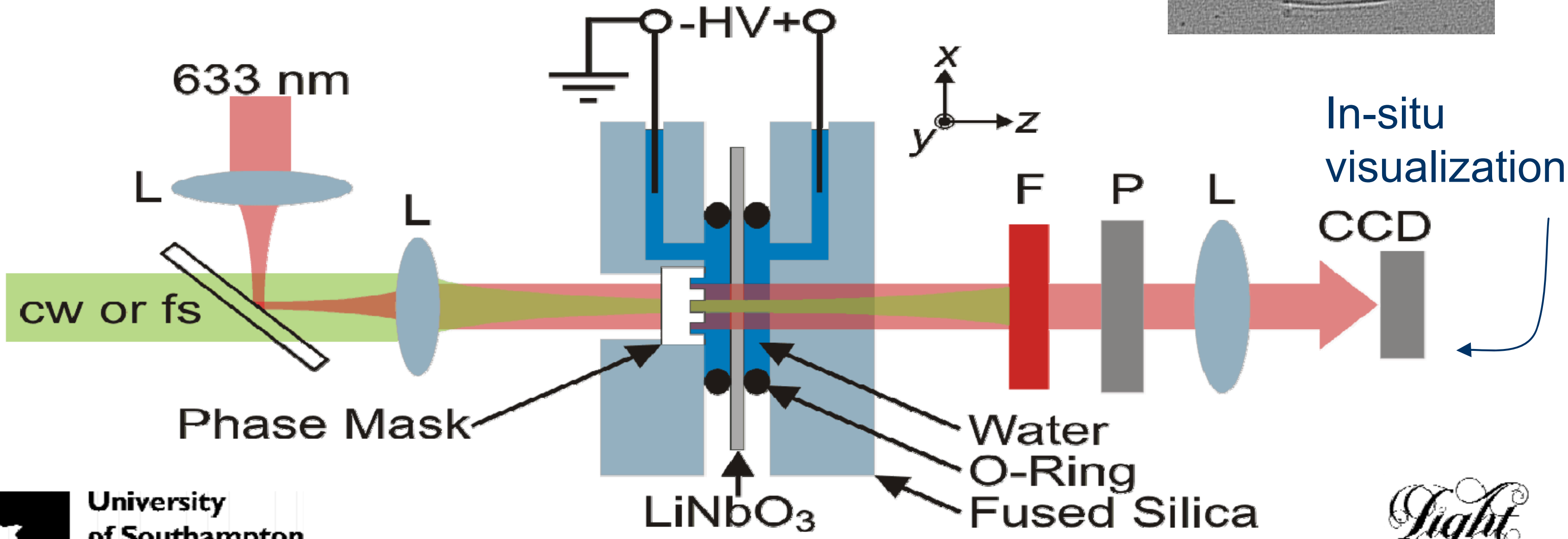
3. Light-assisted poling



3. Light-Assisted Poling (LAP)

- Simultaneously apply:
  - E-field → uniform over crystal
  - Light → conveys pattern





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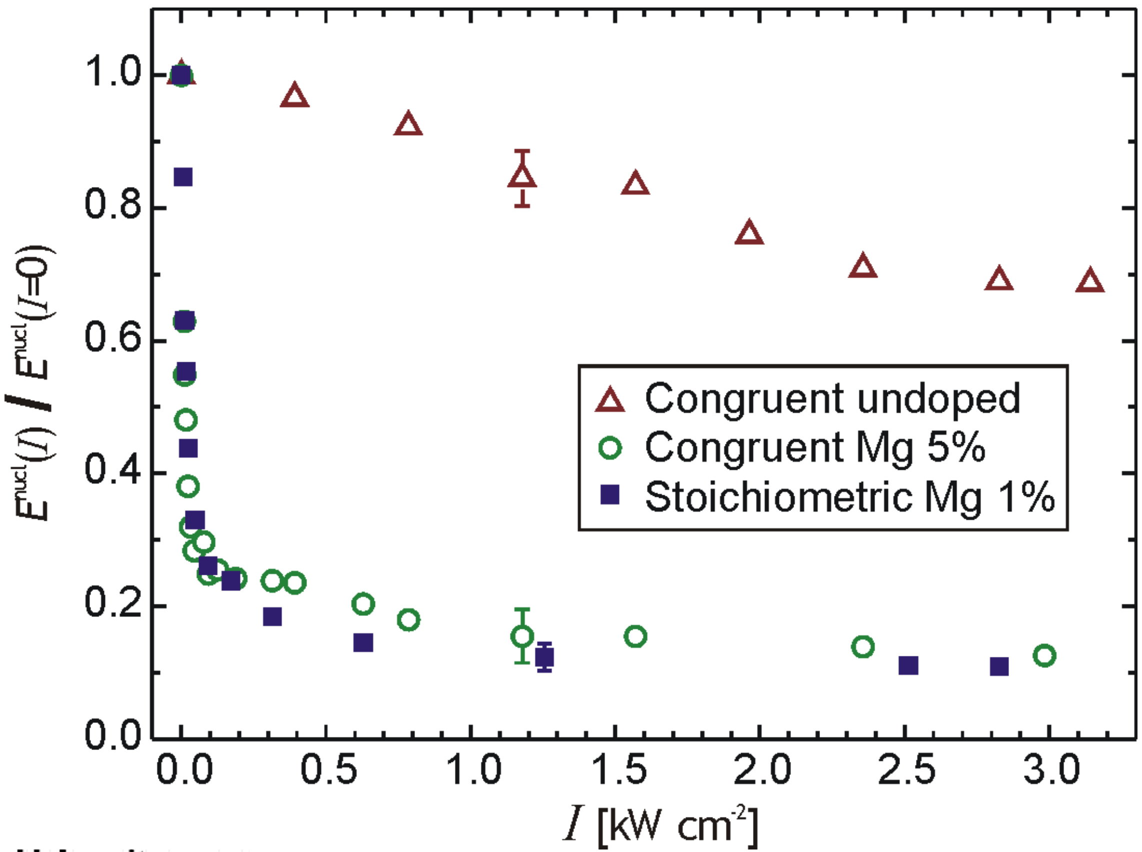
3. Domain inversion (nucleation) c.w



λ= 514 nm
c.w. light

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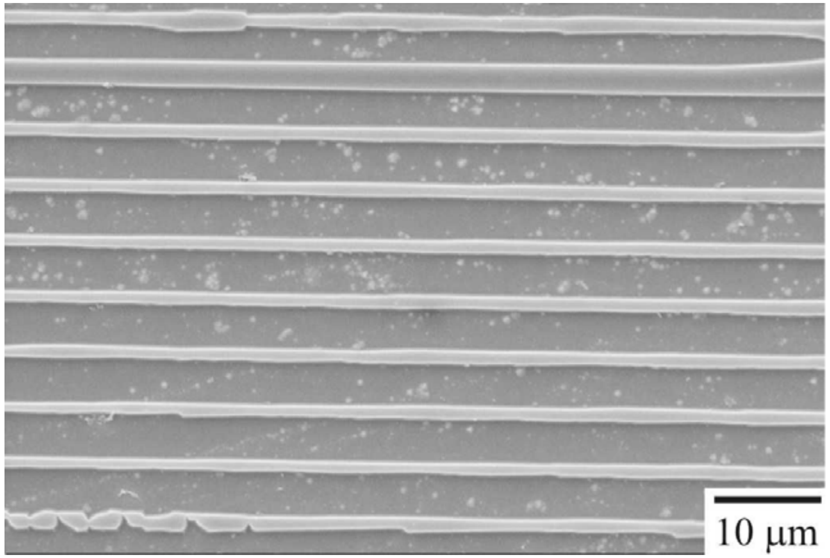
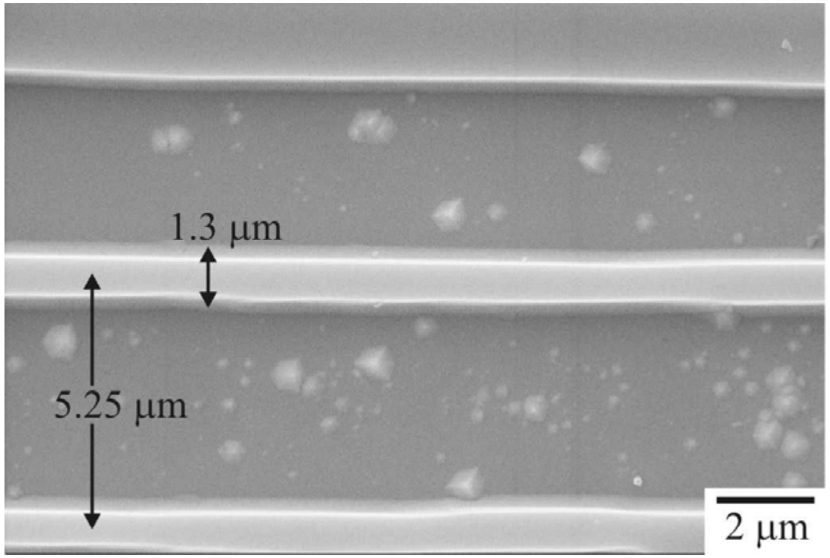
3. Domain inversion (nucleation): fs

- Optically periodically poled lithium niobate (OPPLN)





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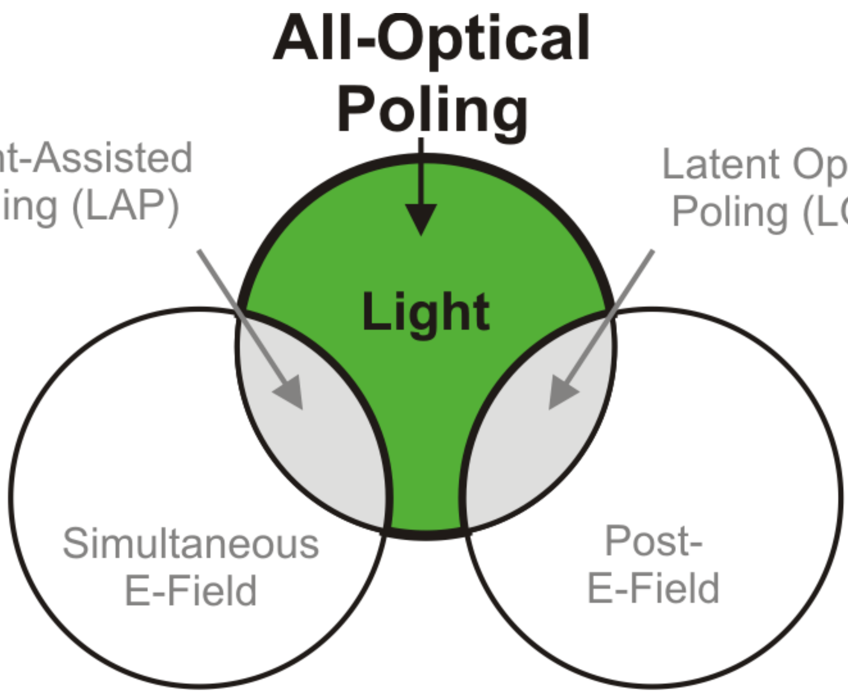
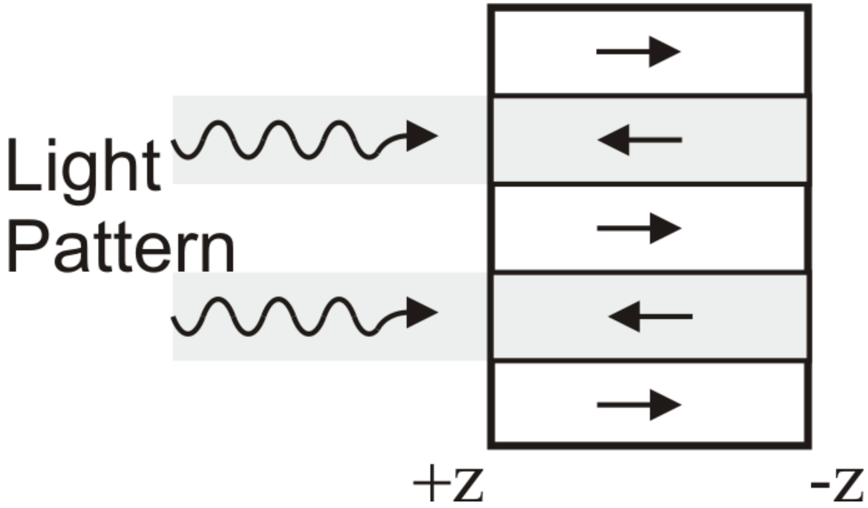
4. All optical poling?



4. AOP



Use structured light to control local poling

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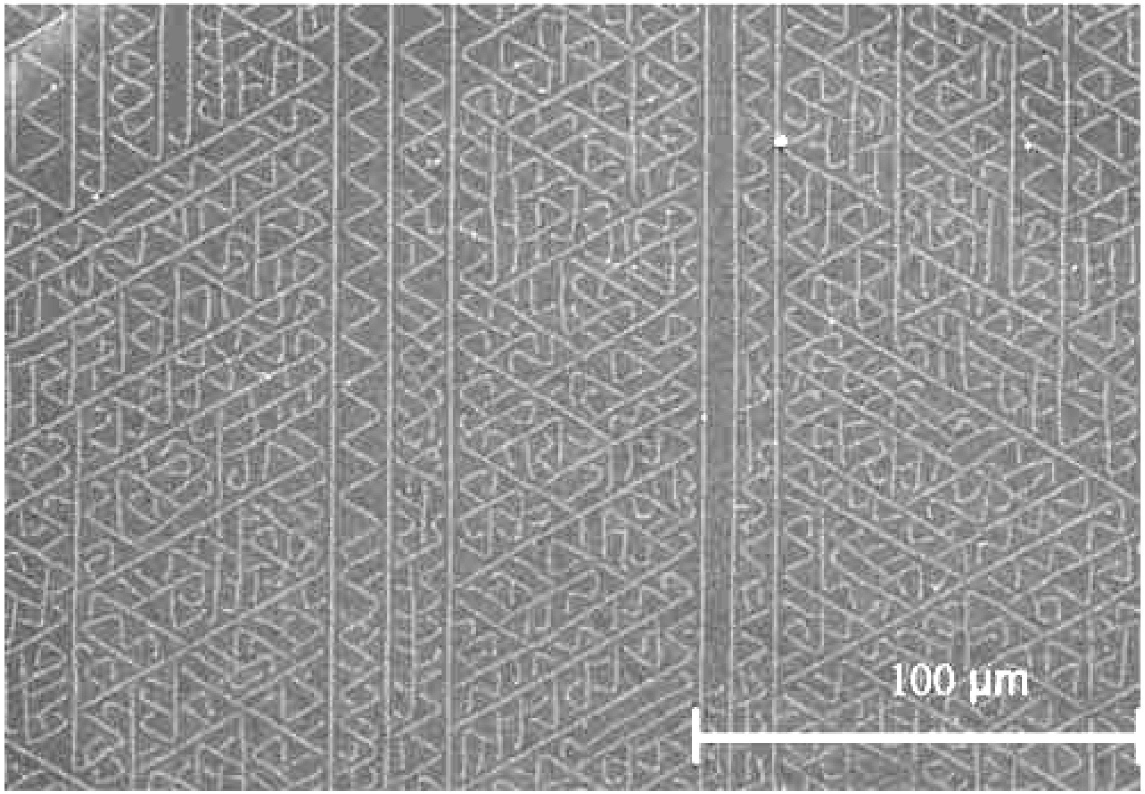
4. All optical poling: unstructured light



Pulsed UV light (CLF tunable dye laser) and 266nm

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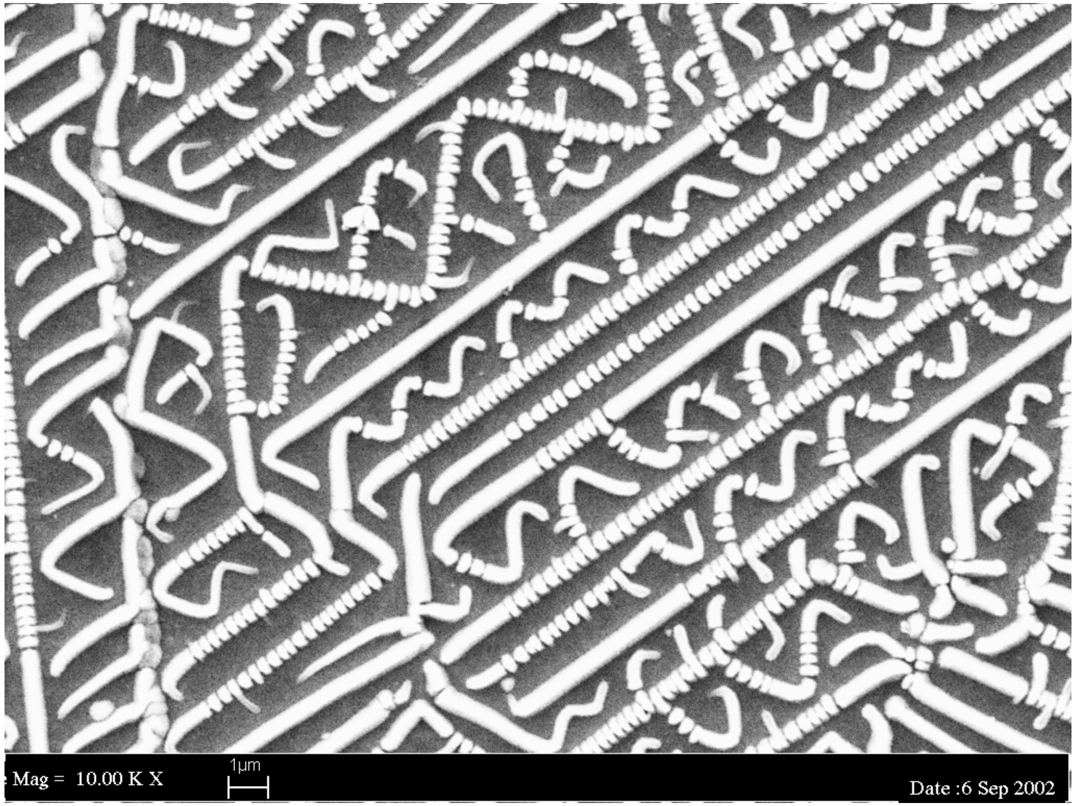
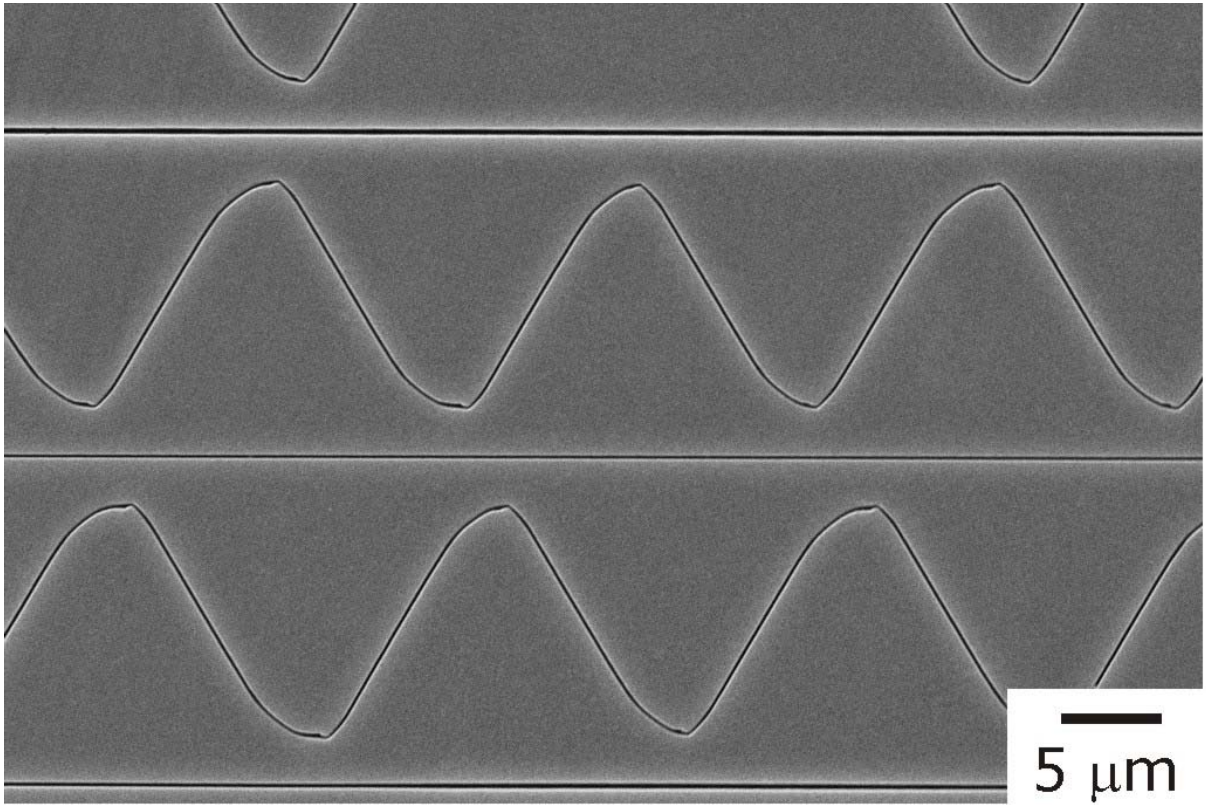
4. Unstructured light: Self-organisation:



10μm

Previous light induced optical patterns using c.w vis light plus HF acid bath

4. Unstructured light: Self-organisation:



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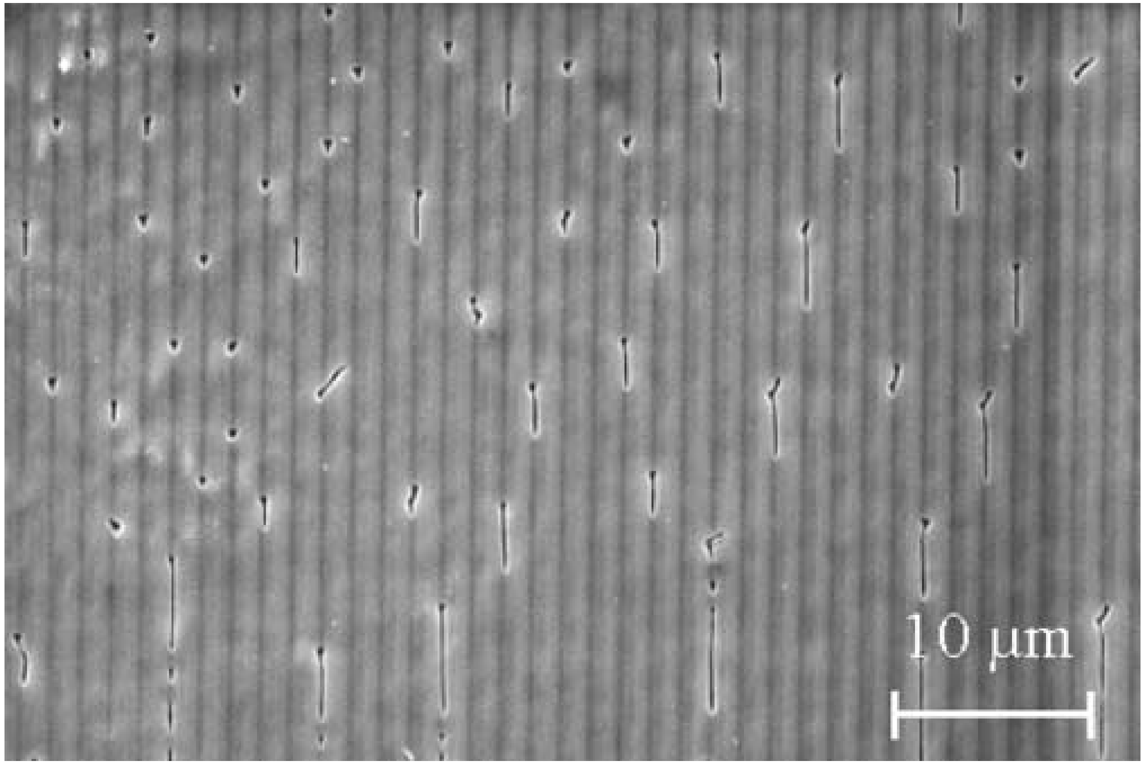
Exotic patterns form.

4. All optical poling: structured light.



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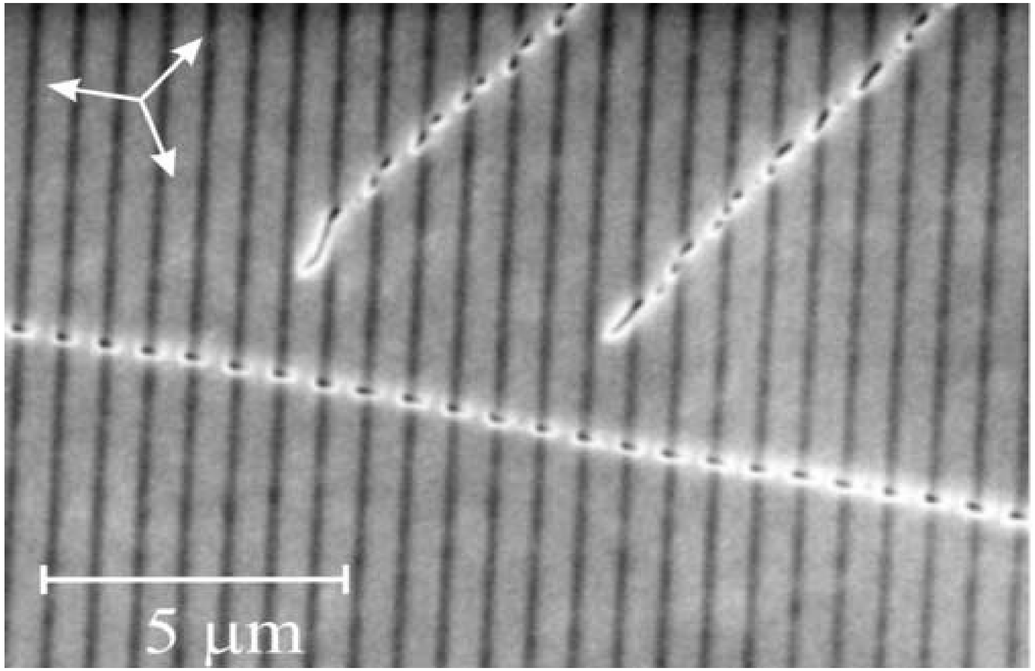
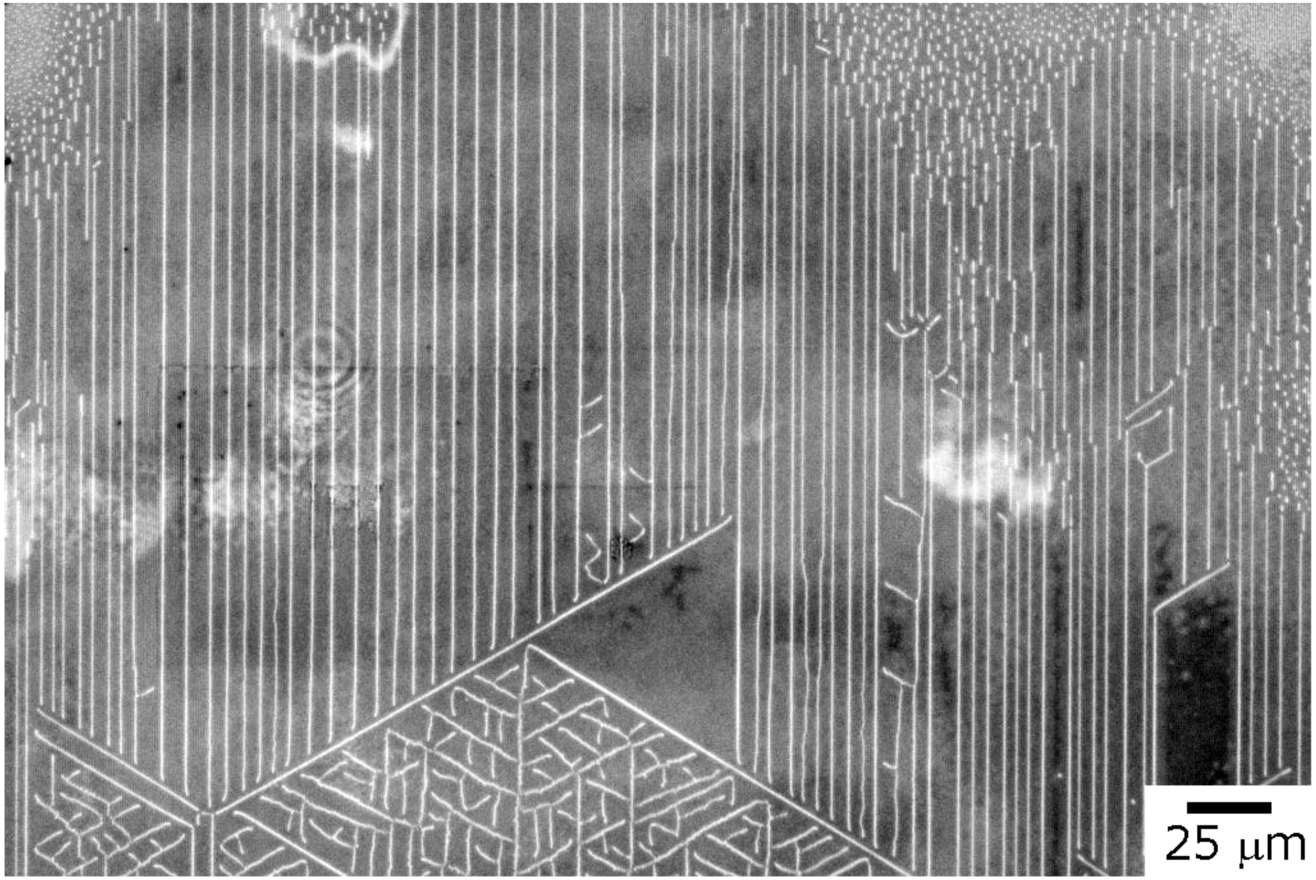
Use of a phase mask for exposure:
Ablation lines + limited domain growth

4. All optical poling: structured light.

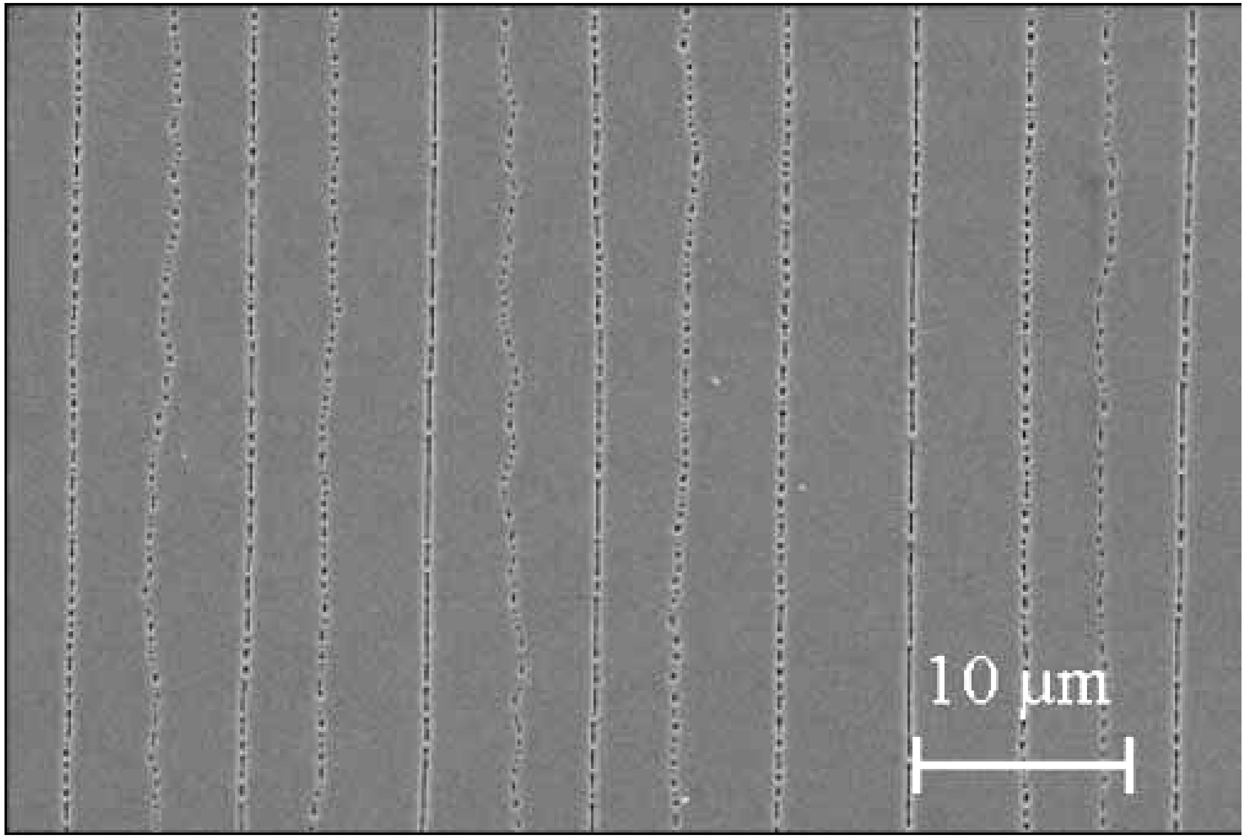


Poling occurs only at local optical maxima.

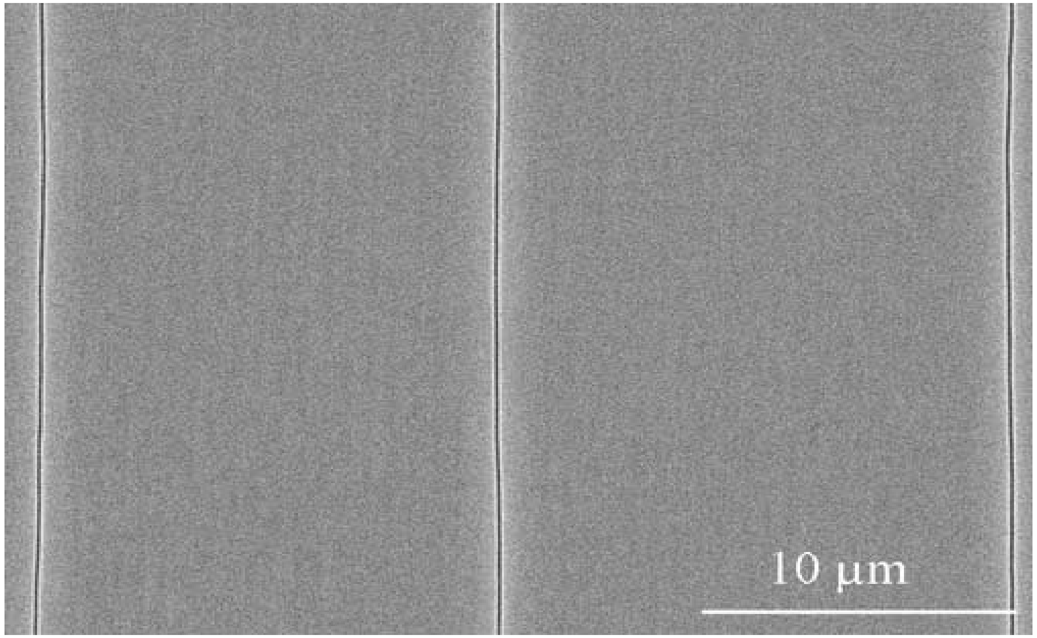
4. AOP: more uniform results.



4. AOP: 'quasi-periodicity'



4. AOP at 150 degrees C



Continuous domain lines:
spacing of 15μm!

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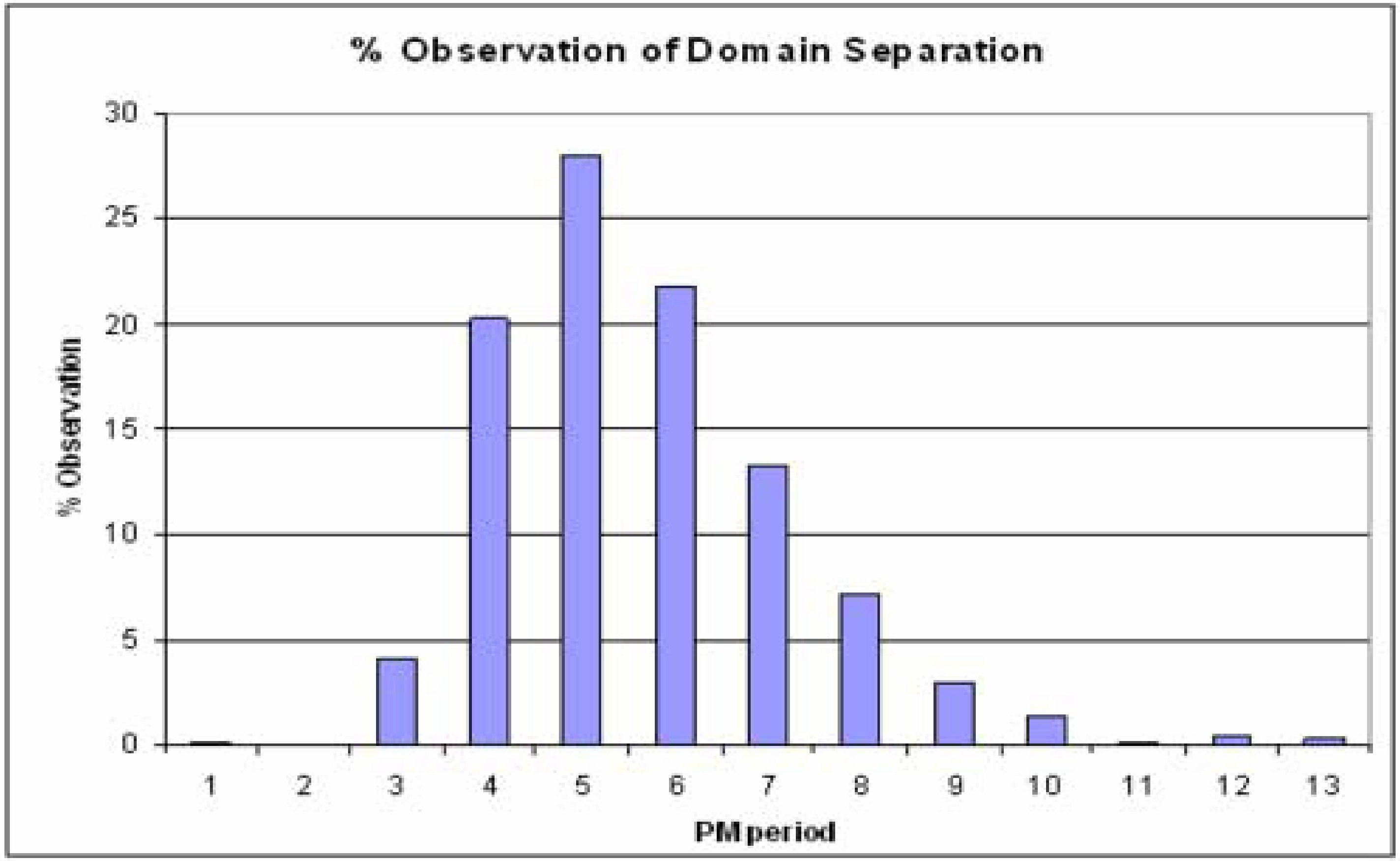
4. AOP periodicity data.



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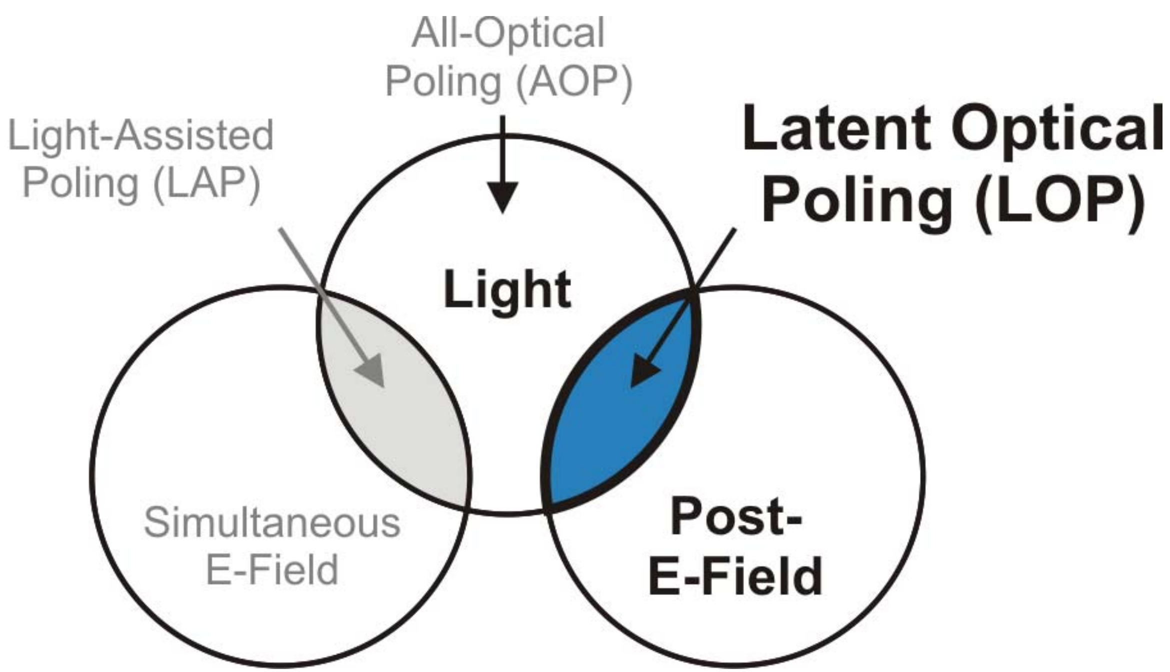
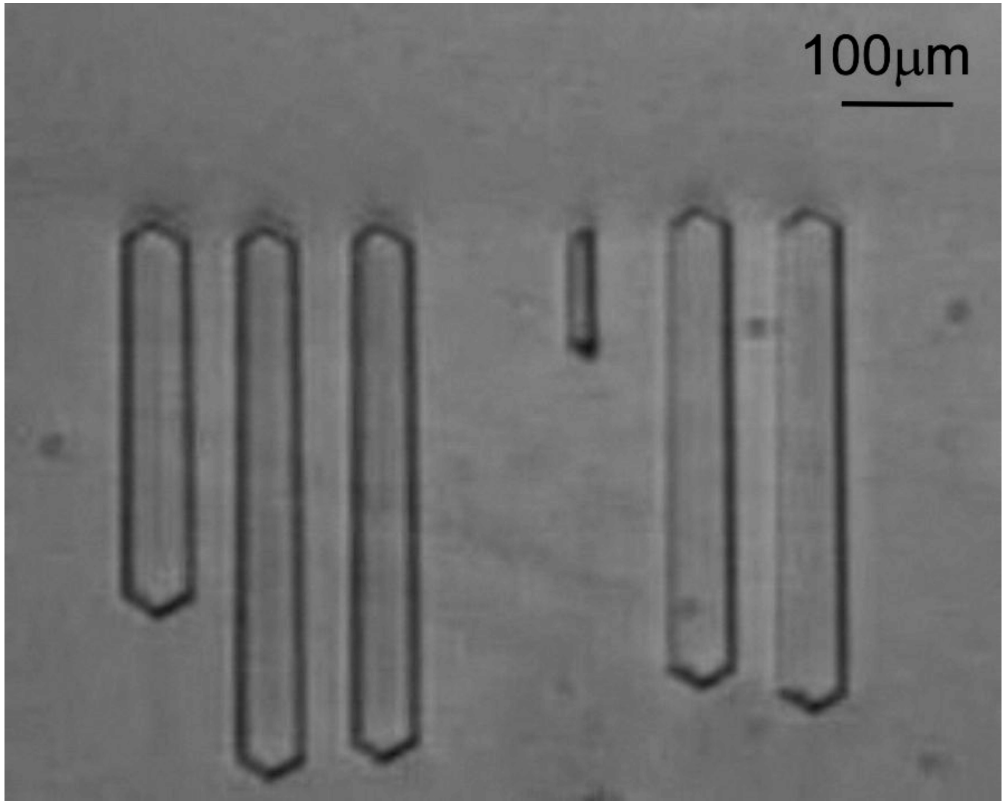
5. Latent optical poling (LOP)



5. Latent poling (FRED laser)



pre-illuminated lines (0.5mm in lengths) scanned (on the +z face) with variable speeds (12.5-50µm/s) at an incident intensity of ~275 kW/cm2.

The image shows the domains formed ~40 minutes after illumination.

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6. Mechanisms

Possible mechanisms:

- Ablation force (piezoelectric) → local E-field
- Local heating (pyroelectric) → local E-field
- Li out-diffusion (unlikely…)
- Photoconductivity modification (possible)

  M. Wengler JAP 2005 (λ = 304 nm):

  highly absorbed UV light modifies the E-field distribution due to non-uniform conductivity induced by photoconductivity

6. Mechanisms/conclusions

- **AOP** does not produce closely spaced domain features:

  electrostatic repulsion in weakly interacting system.

- **LAP** does produce these features, and fs looks most promising.

  scanned exposure produced good quality OPPLN

- **LOP** may be the best of all: = photographic printing.

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Publications and acknowledments

- Publications listed at
  http://www.orc.soton.ac.uk/intaltpub.html
- Thanks to CLF staff:
  - Ian Clark in particular.

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