Picosecond Laser Machining of Optical Fibre Based Cantilever Sensors

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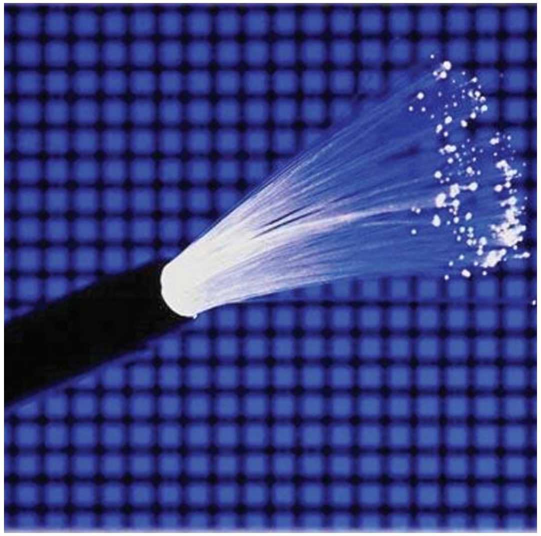
- Introduction
  - Fibre sensing
  - Cantilevers
  - Picosecond laser manufacturing
- Fibre cantilever design and operation
- Manufacturing setup and process
- Results

Fibre optic sensing

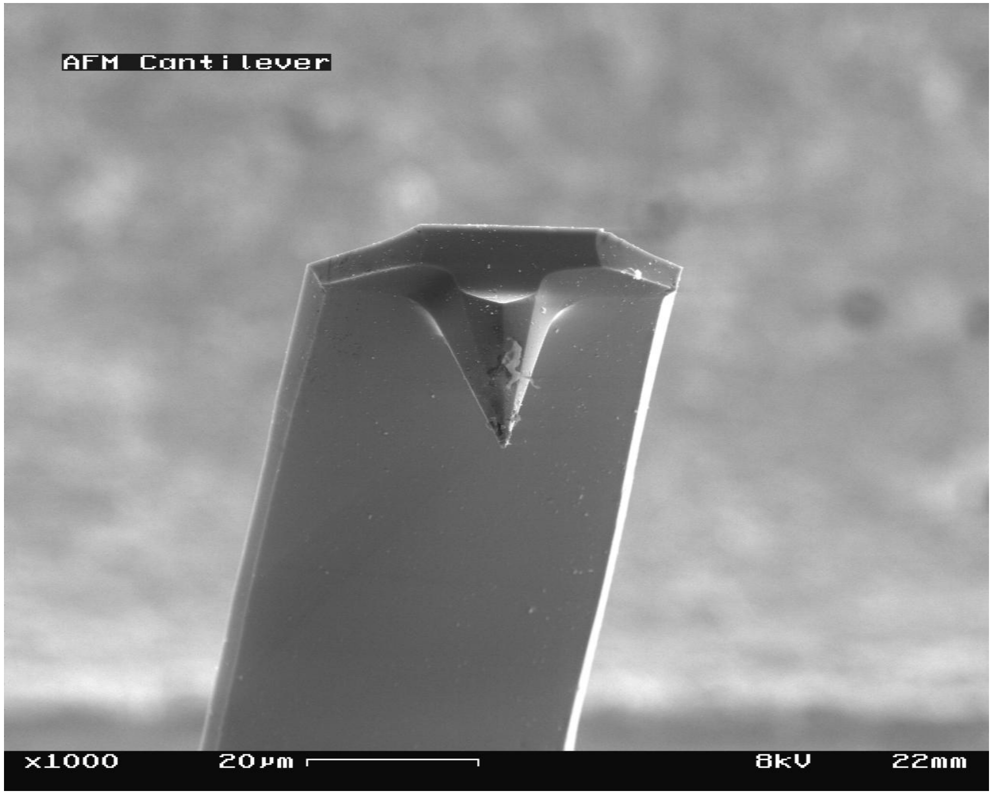


Advantages of fibre sensing:

- Small (typ. Ø=125 µm)
- Temperature stability
  (up to 1000 ˚C in some applications)
- Long distance to analytical instruments
- Large variety of sensing possibilities
- High accuracy and no alignment needed (in our case)
- Good knowledge of fibre technology

Cantilevers

- Well known (AFM)
- Many application areas
  - Vibration
  - Acceleration
  - Force
  - …
- Bio-medical applications enabled through coatings

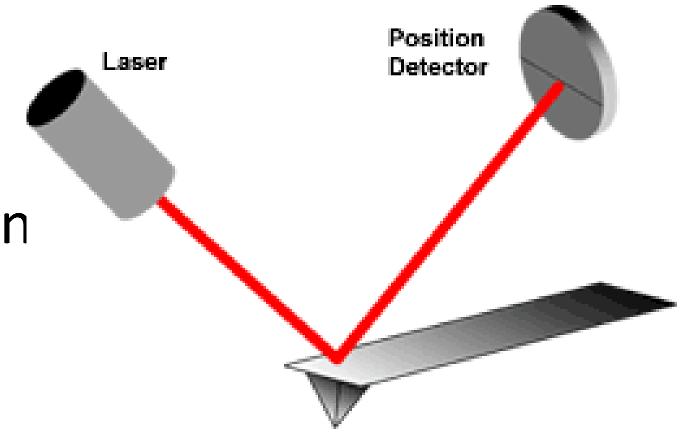


http://commons.wikimedia.org/wiki/File:AFM_(used)_cantilever_in_Scanning_Electron_Microscope,_magnification_1000x.GIF

Advantage of optical sensing

Conventional cantilever interrogation:

- Piezo-resistive method
  - Constraint in some EMI environmen
- Optical beam deflection
  - Alignment is complicated



Optical fibre cantilever

- High accuracy and no alignment during fabrication
- Combining sensing and interrogation
- Enable applications in space constrained environments

Fibre cantilever design

Light traveling in the fibre

↓

Reflection from end of fibre

↓

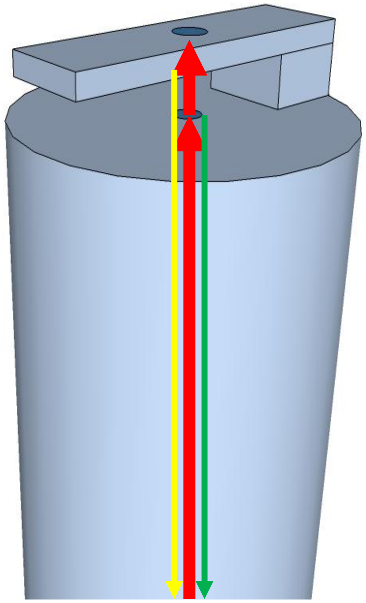
Reflection from cantilever

↓

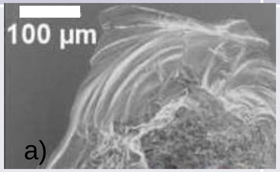
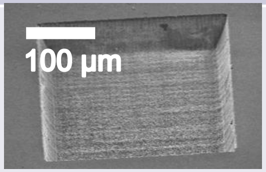
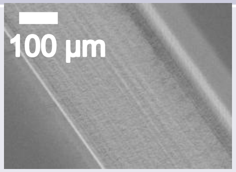
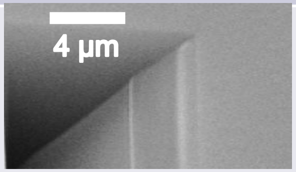
Interference signal

↓

Change of cavity size is detected



Comparison of different machining methods

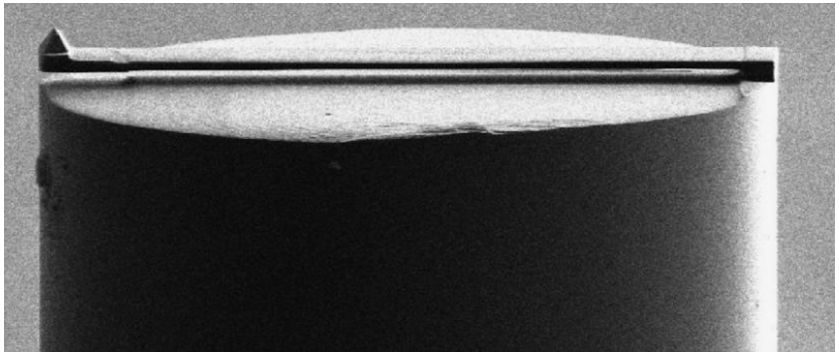
	ns-laser	ps-laser	fs-laser	Focused Ion Beam
Heat affect zone	Large	small	small	N.A.
Ablation rate	very high	high	Low (limited by av. power)	lowest
Surface finish	cracking	scattering (R_a≈400nm)	scattering (R_a≈200nm)	Optical quality (R_a<10nm)
Examples				

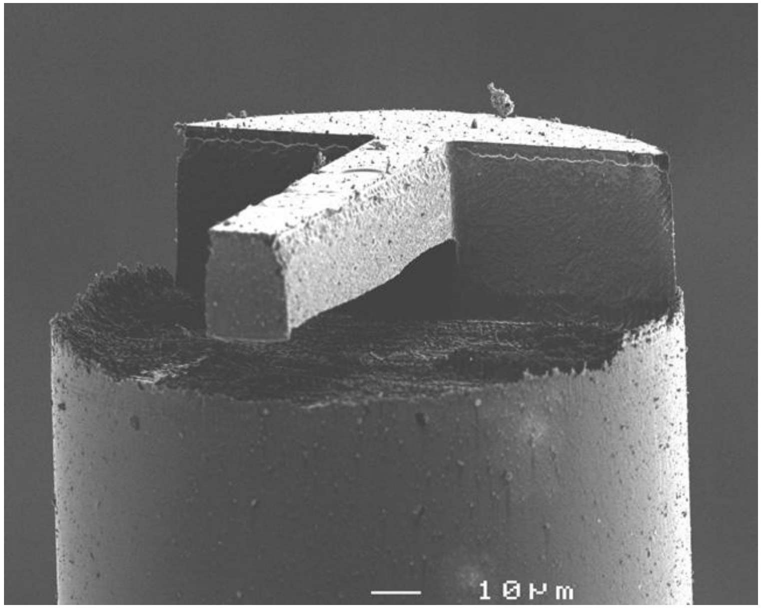
a) Raluca A. Negres, Mary A. Norton, David A. Cross, and Christopher W. Carr
Optics Express, Vol. 18, Issue 19, pp. 19966-19976 (2010)

Previous work

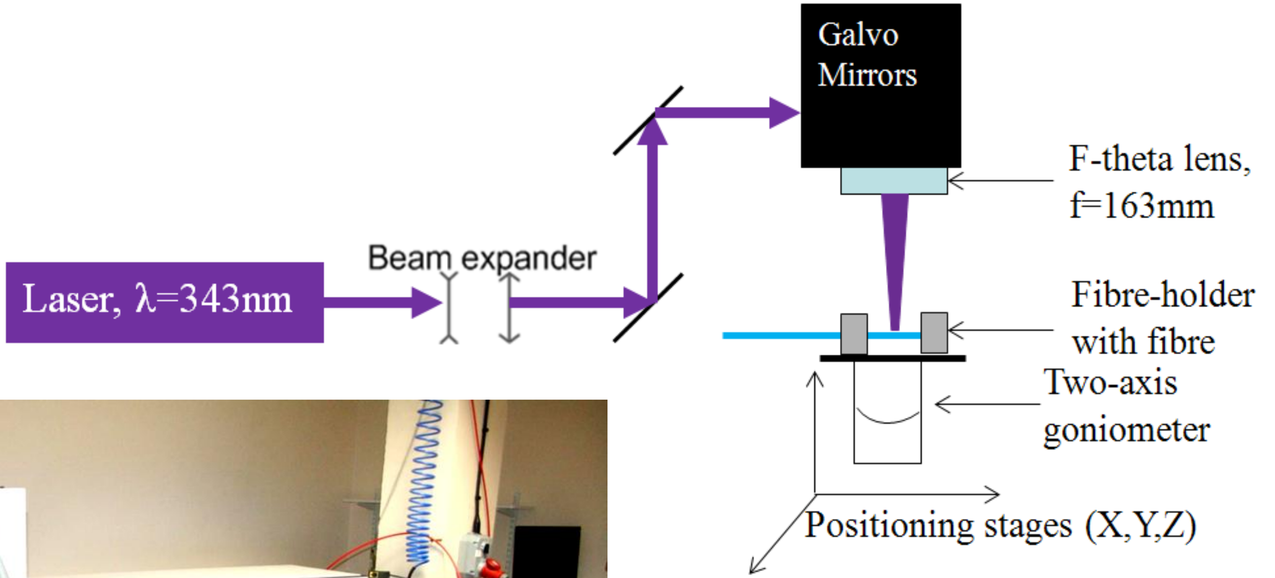
- Previous work on fibre-top cantilever
  - Using FIB machining (very time consuming ~4h)
  - Femtosecond laser + etching (two processing steps ~1h)

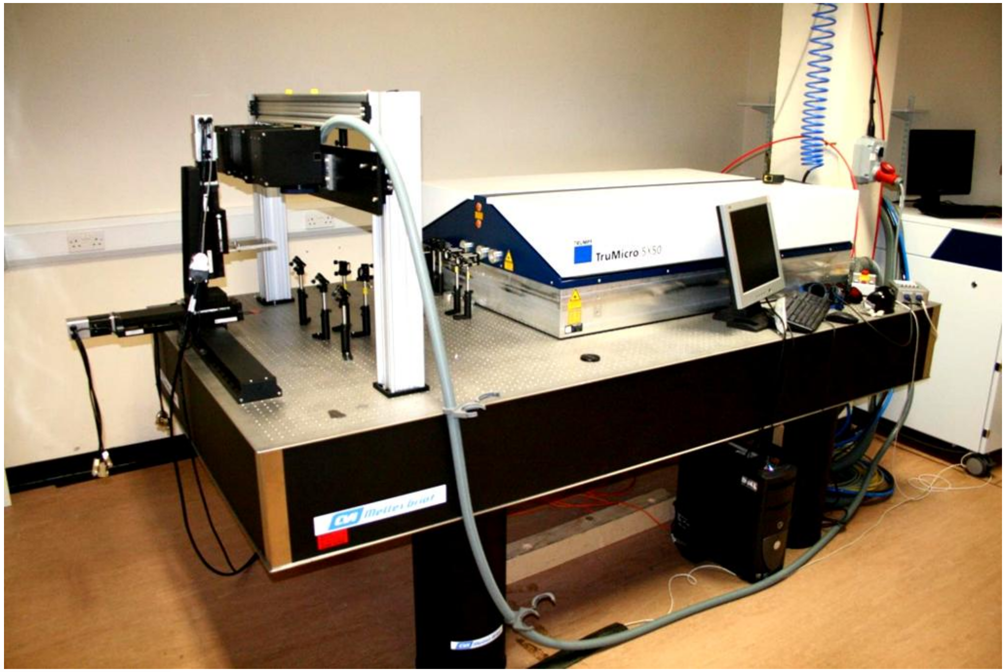
(D Iannuzzi et al. "Carving fiber-top cantilevers with femtosecond laser micromachining",2008, J. Micromech. Microeng. 18 035005;
D Iannuzzi et al, " Fibre-top cantilevers: design, fabrication and applications", 2007 Meas. Sci. Technol. 18 3247)





Manufacturing setup



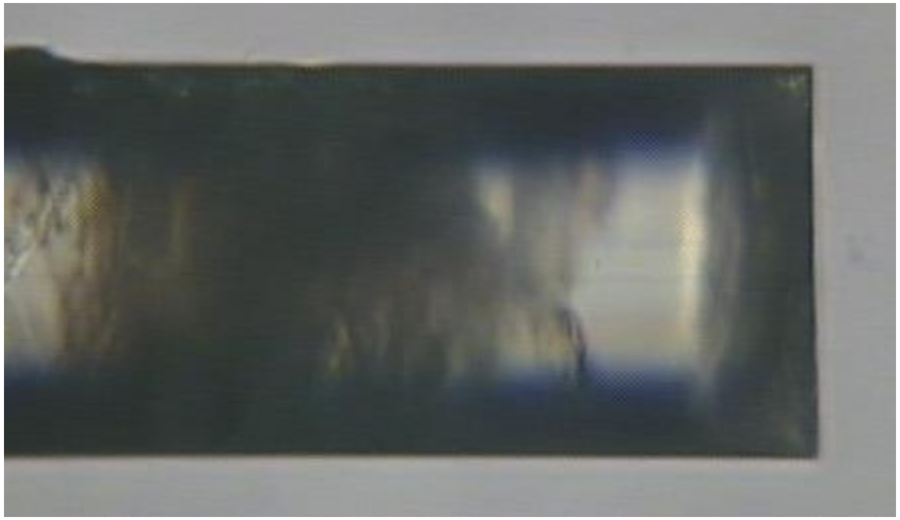


Challenges of the design

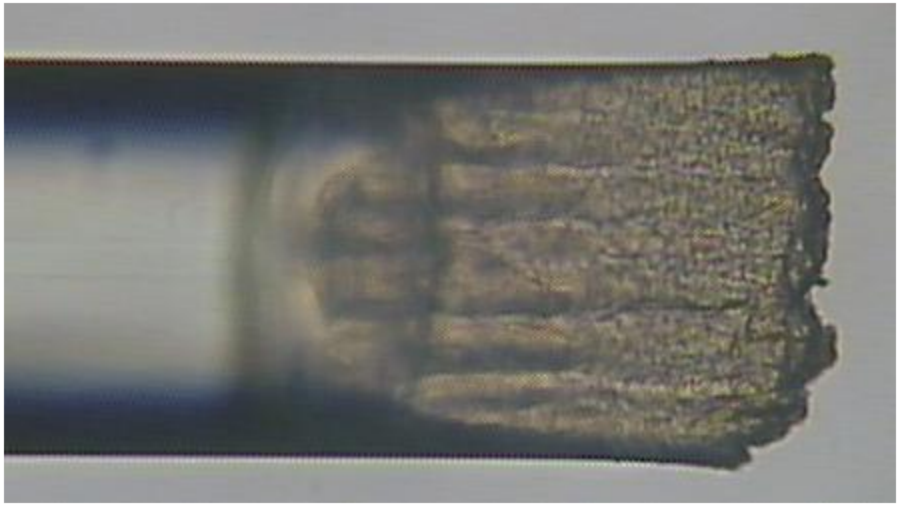
- Cantilever less than 10 µm thickness
- No cracking in fibre and cantilever
- Optical or near optical quality of the surfaces
- Very good control over the wall angle
- Short machining time
- Scalability for industrial production

Cracking due to chosen energy

- Low energy cracking in fibre at 6 µJ pulse energy

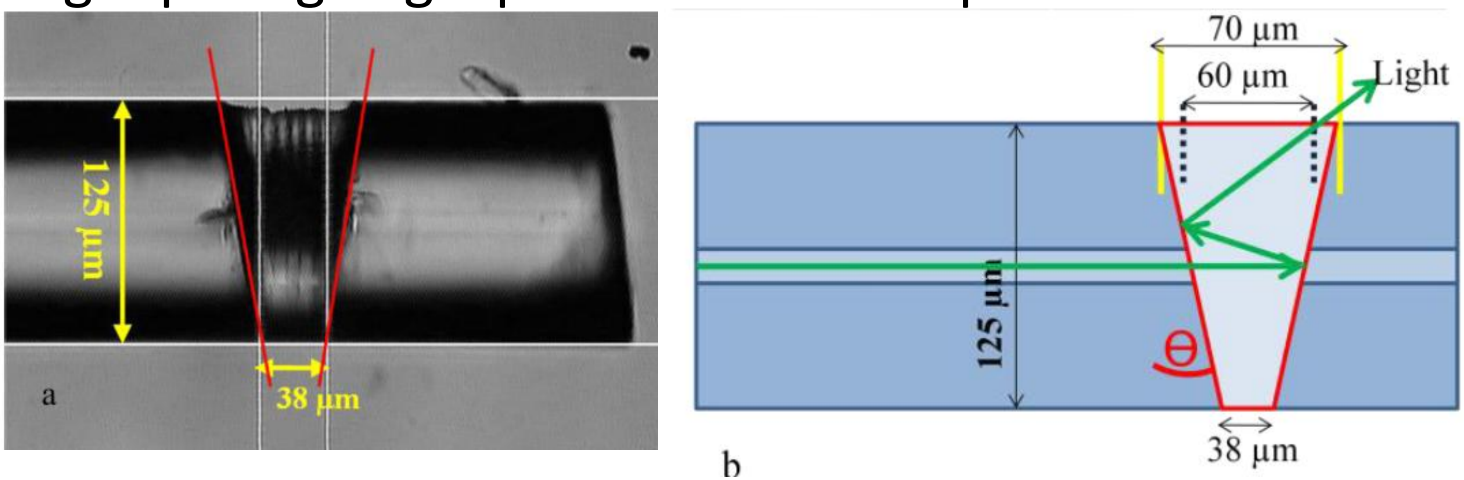


- High energy cracking in ridge at 16 µJ pulse energy



Challenges

- Strong tapering angle prevents sensor operation



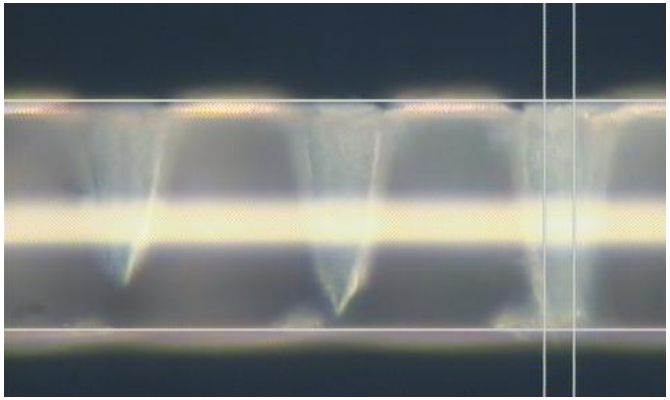
- Possible Solutions:
  - Optimization of laser parameters (correlation between pulse energy and tapering angle)
  - Goniometers for rotation by desired angle

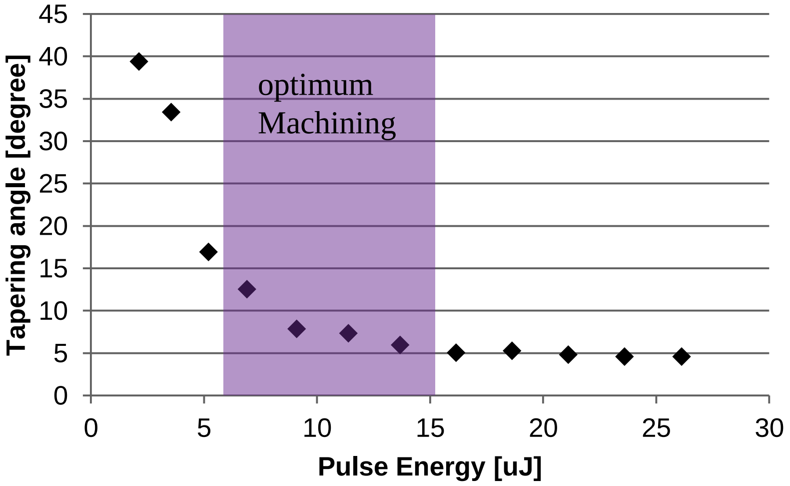
Laser machining a fibre

- Wall angle depending on pulse energy
- Cracking at to high energy
- Cracking deeper inside fibre with to low energy

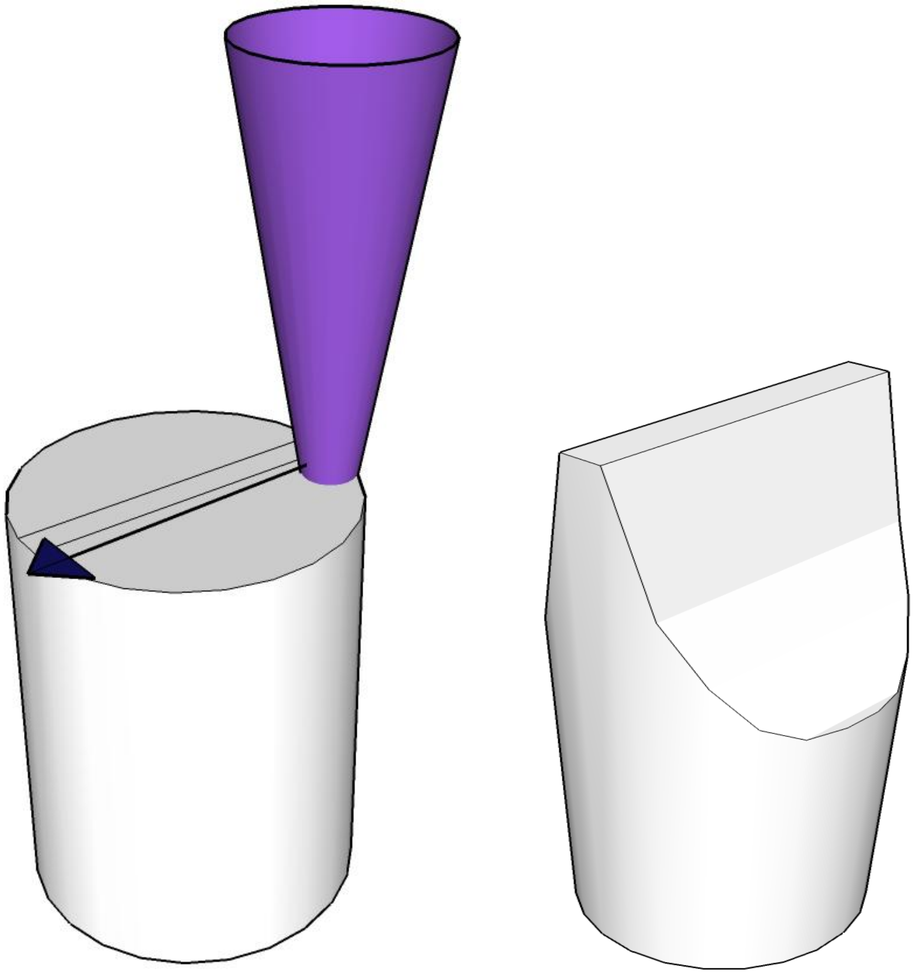
➢ Find energy for lowest cracking

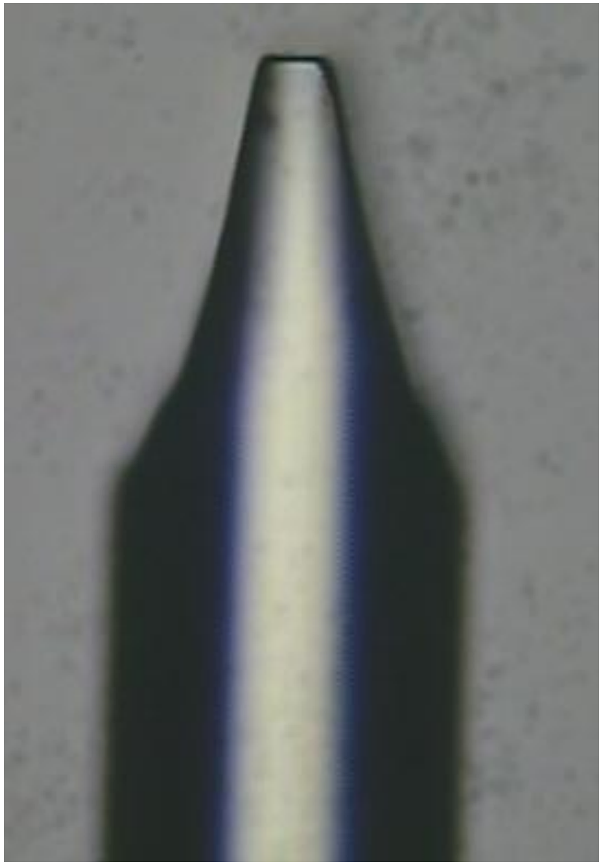
➢ Correct for wall angle





Scheme of machining





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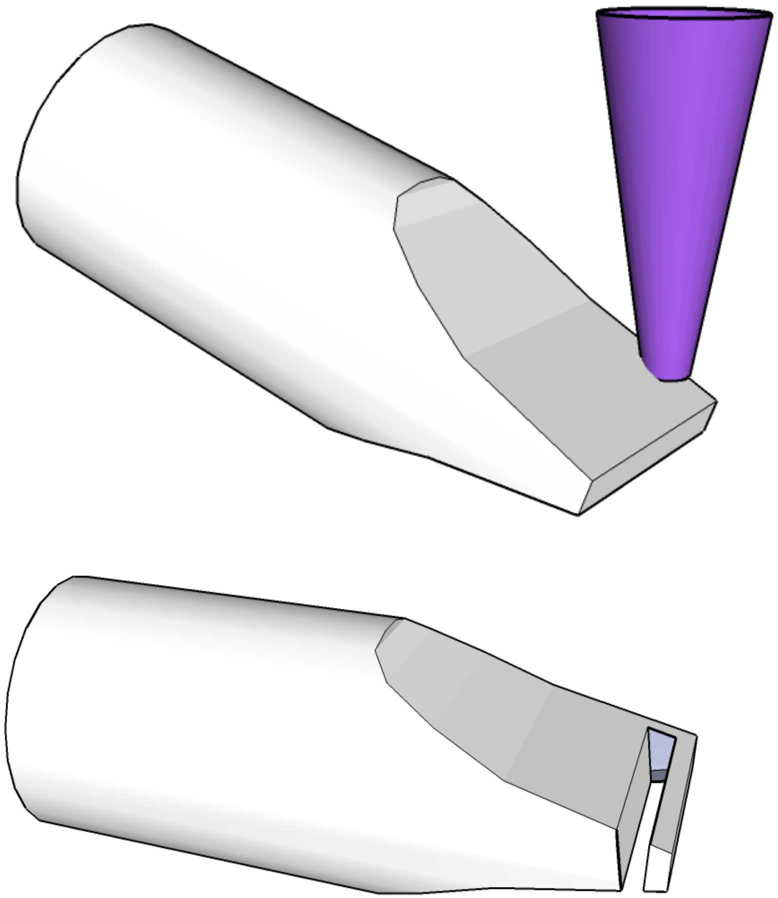
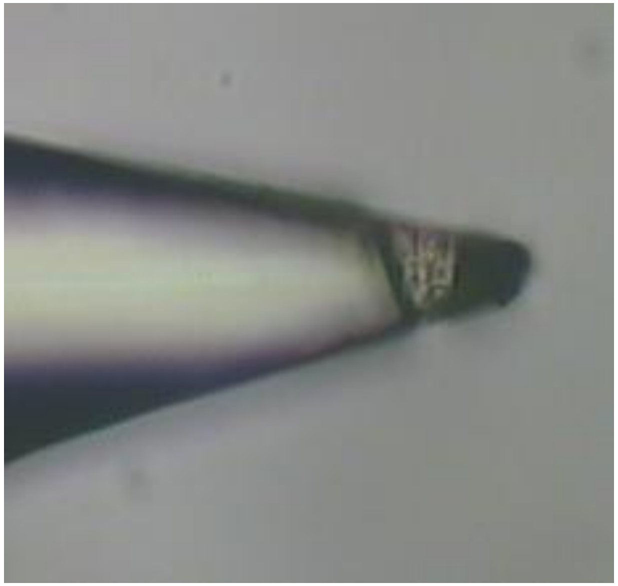
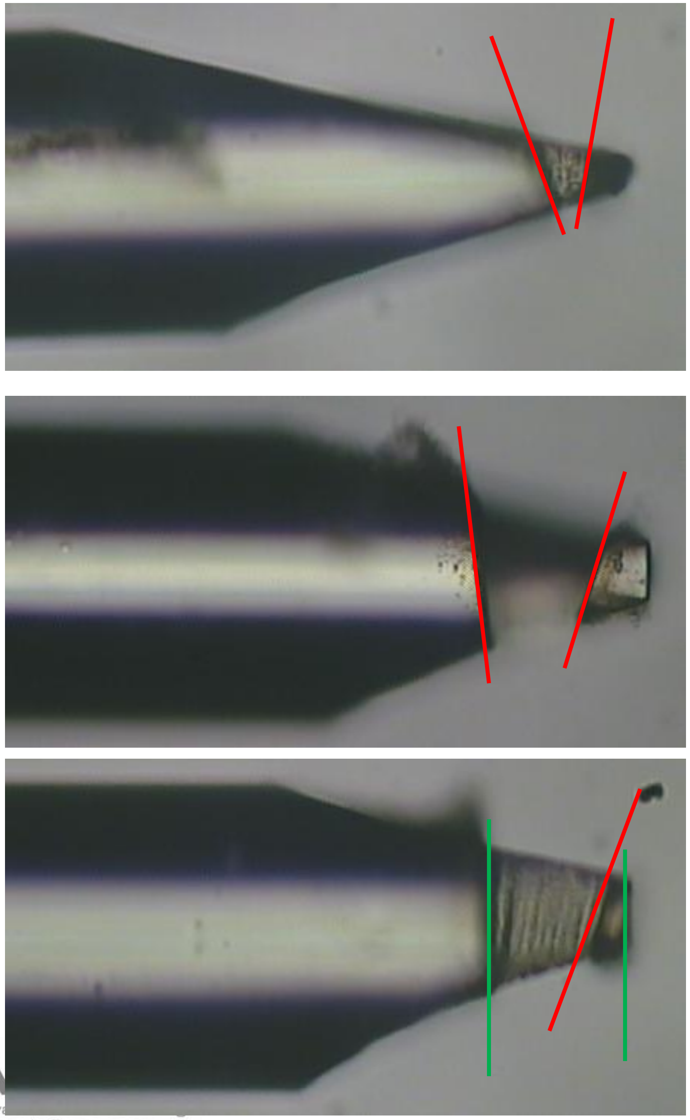


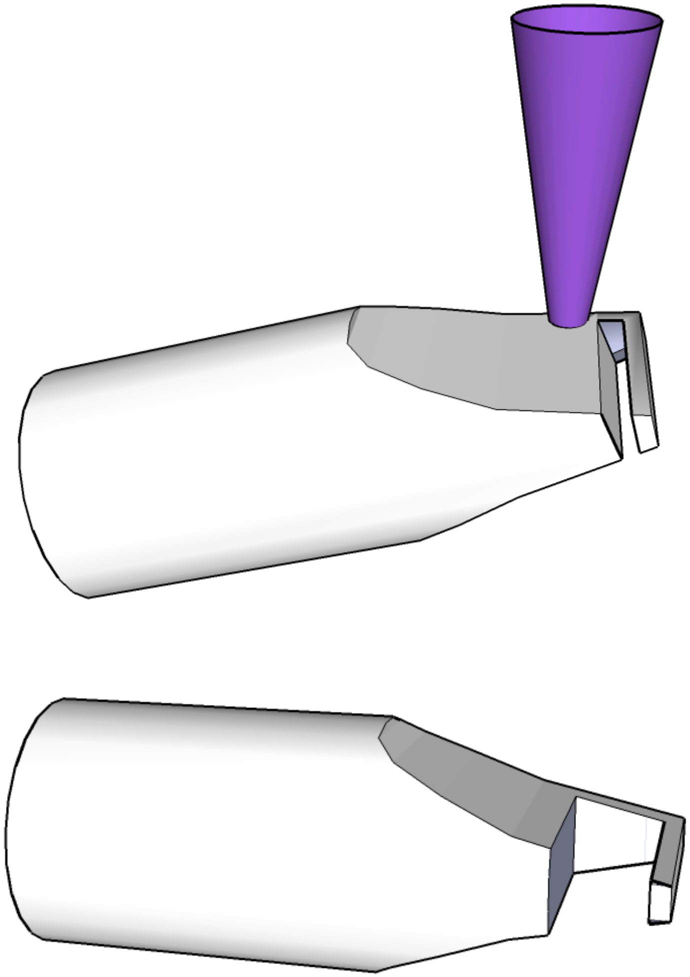


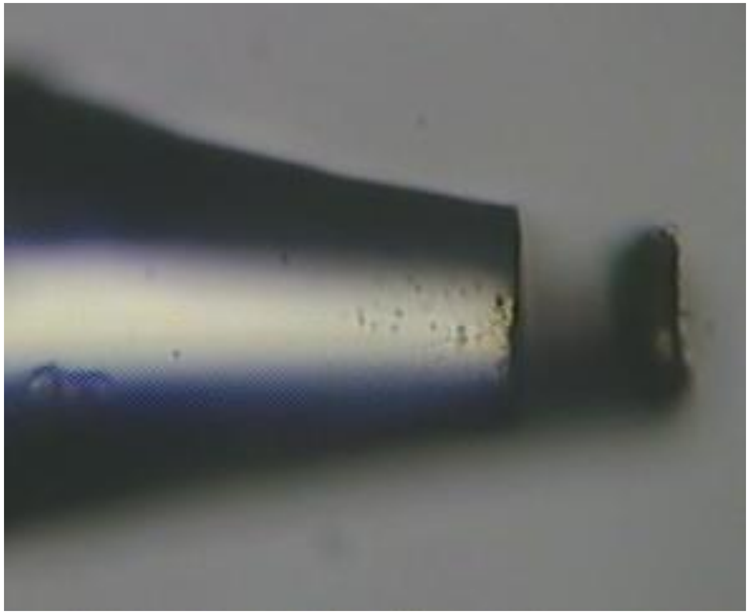
Achieving parallel surfaces



- Without tilting the fibre
- Tilted 8˚
- Tilted 12˚

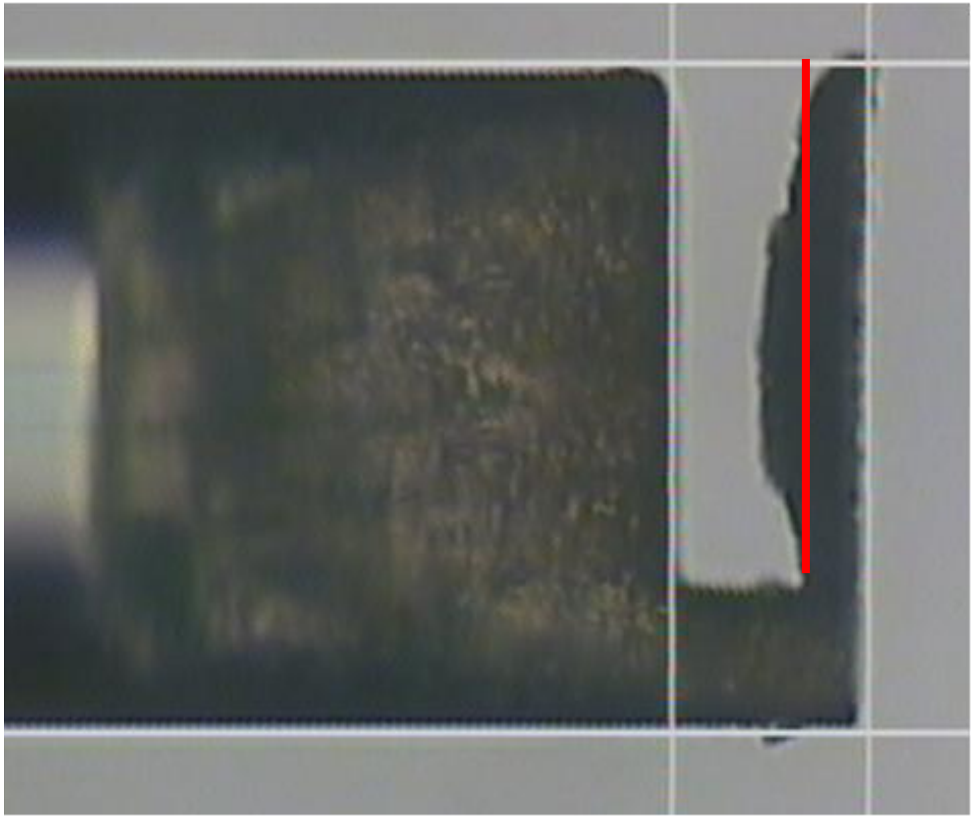
Second cut for parallel surfaces



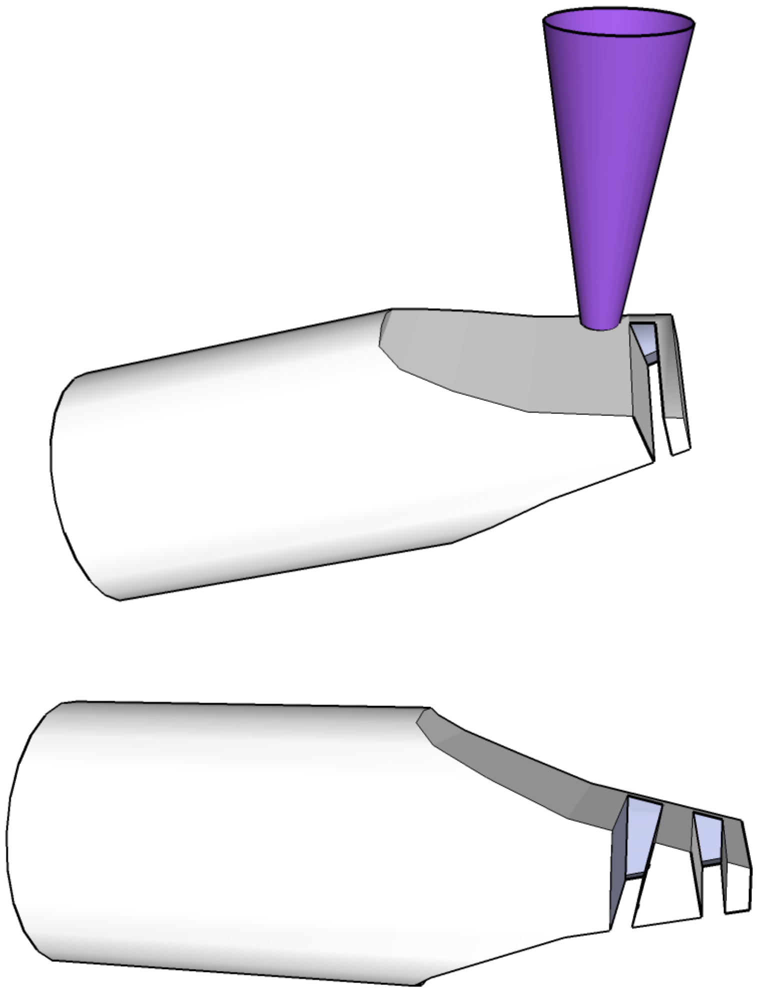


Problem with debris deposition

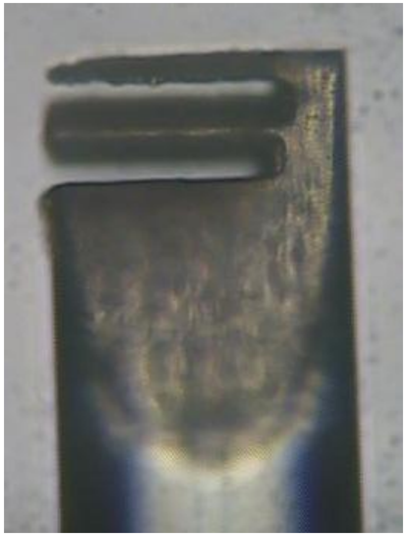
- 5µm thick layer of debris in centre
- Not removable with Ultrasonic bath
- Reduces signal



Second cut for parallel surfaces

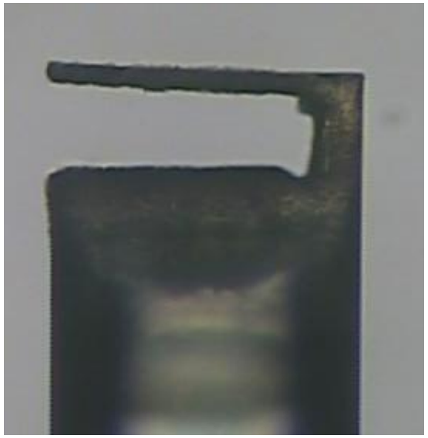


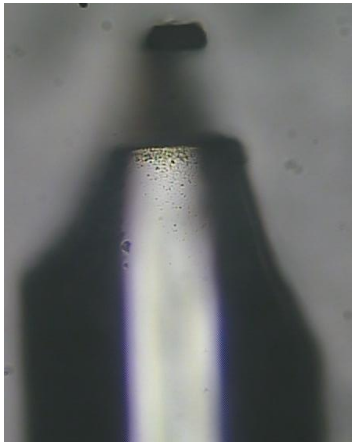
- Central structure collects debris
- Only very small cut needed to remove

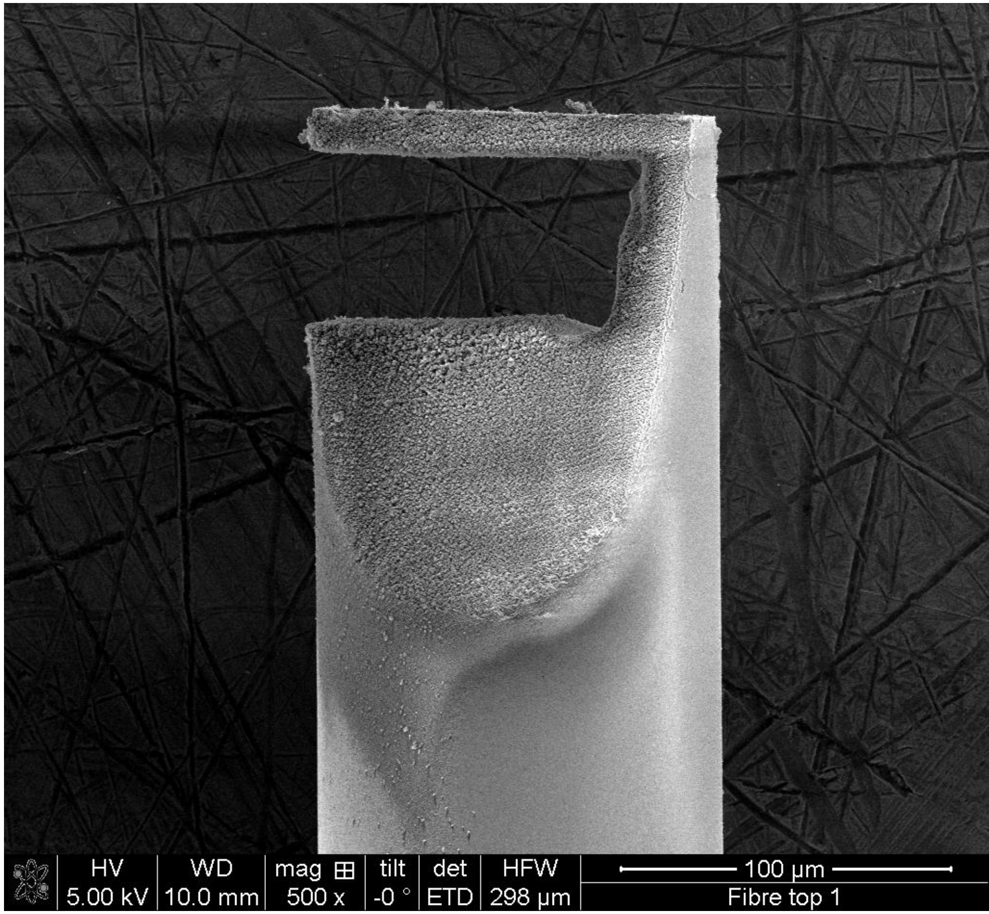


Second cut for parallel surfaces

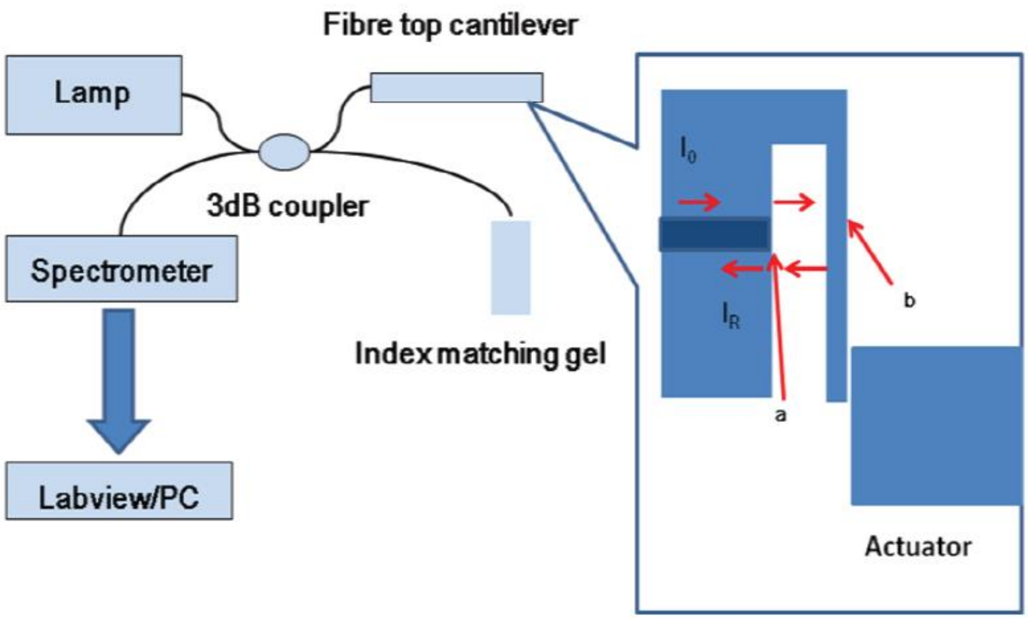
- All surfaces parallel
- Low debris deposition
- Repeatable with less than 10 µm thickness

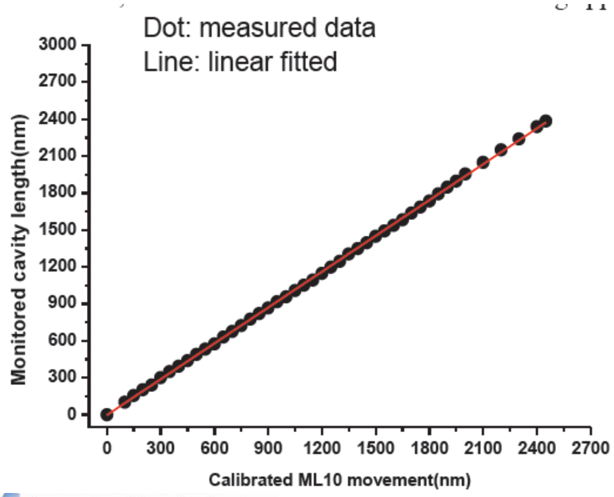


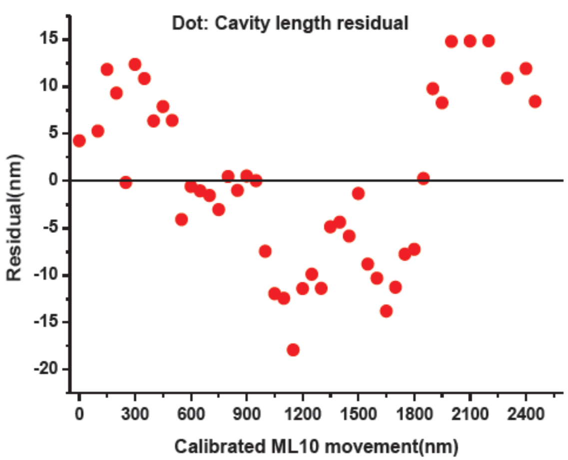


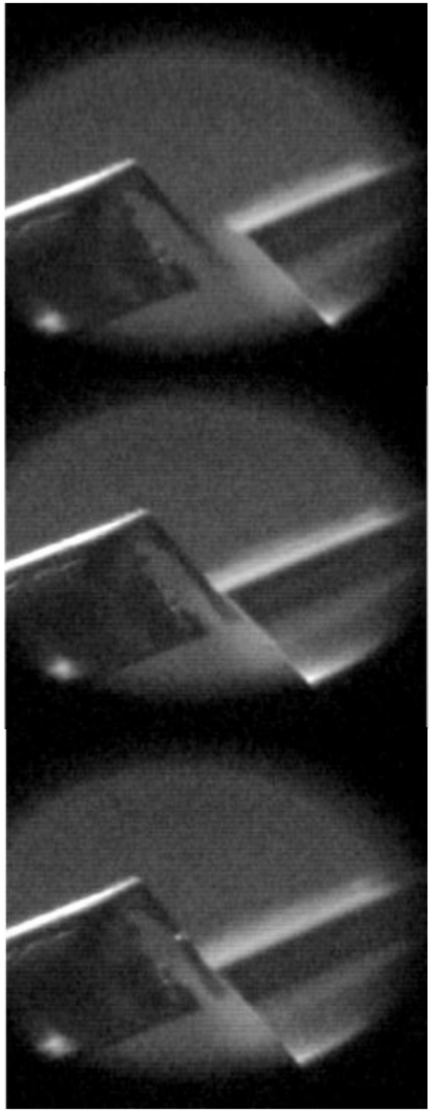


Actuation example









Conclusions

- Cantilever structures out of fused silica fibre by ps-laser ablation
- Used as sensors for simple actuation experiments
- Stable results over 2.7 µm actuation
- Accuracy of < 10 nm
- Manufacturing time for a cantilever < 1 min.
- Process easily adopts to mass manufacture

Acknowledgments

EPSRC
Engineering and Physical Sciences Research Council

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