James Watt Institute *for* High Value Manufacturing

Advanced Micro-machining of Optical Fibre Cantilever Sensor

J. Li, F. Albri, J.N. Su, R.R.J. Maier , W.N. MacPherson, D.P. Hand

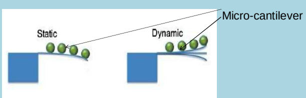
HERIOT WATT UNIVERSITY

Introduction

Micro-cantilever sensors are attracting much attention as promising solutions for highly sensitive detection of bio-molecules without the need for fluorescent or radioactive labeling.

Bio-molecules are selectively attracted to one side of the cantilever only. Attached molecules induce mechanical bending which can be precisely detected using optical methods that are routinely used for atomic force microscopy (AFM). However, conventional AFM techniques involve bulky optical beam detection systems that are unsuitable for in-vivo measurements.

Optical fibres are ideal medium for high accuracy deflection measurements using optical interferometry. In this research we aim to manufacture micro-cantilevers onto the end of an optical fibre thereby combining the sensing element and the interrogation system into one compact device to enable bio-sensing applications in space constrained environments.



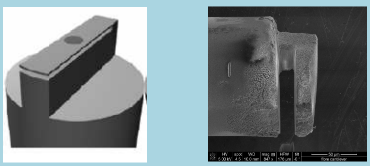
Micro-cantilever with bio-molecular attached onto the surface. Left static mode, right dynamic mode (Courtesy of Lifan Liu)

Fabrication Process

Micro-machining of fibre top cantilever

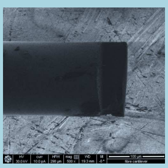
Previous work [1] reports Focused Ion Beam (FIB) machining for fabricating optical fibre cantilevers. Here the combination of ps-laser machining techniques together with FIB is employed to fabricate a fibre top cantilever.

We first use a ps-laser to machine a ridge on top of a SMF-28 corning fibre, then use FIB to remove part of the material inside the ridge forming a suspending cantilever structure.

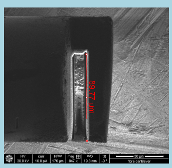


3D Model (left) and SEM (right) view of fibre top cantilever

- ***Cantilever structure size:***
  - *90μm long, 37μm wide, 25μm thick ;*
  - *FIB machined Fabry-Perot cavity length is 16μm.*
- ***Surface finish:***
  - *Machined surface roughness by ps-laser is R_a:100-300nm*
  - *Machined surface roughness by FIB is R_a:3-5nm.*
- ***Advantages:***
  - *Total machining time is greatly reduced;*
  - *An optical surface finish is achieved by FIB;*
  - *Industry reliable ps-laser machining is fast and mass production;*



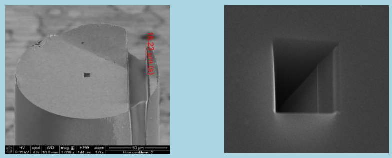
ps-laser machined ridge



FIB finished fibre top cantilever

Fabrication of fibre side cantilever

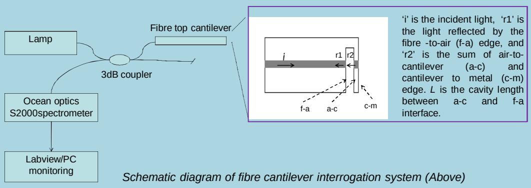
The aim of fabricating cantilever on side of an optical fibre is finally try to manufacture a 3D optical probe with a multi-core fibre for biomedical application.



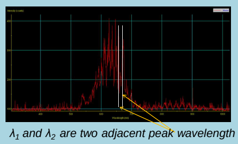
FIB machined fibre side cantilever (left), 45° mirror (right)

- ***Characteristic:***
  - *Fused silica fibre: outer diameter 125 μm, core diameter 5 μm;*
  - *Light from the core is reflected by 90° at the 45° mirror;*
  - *The length of the fibre side cantilever: 18.22 μm, thickness ~10 μm;*
  - *It could be used for space constraint and in-vivo detection.*

Cantilever interrogation



Schematic diagram of fibre cantilever interrogation system (Above)



$$I_r = 2RI_0\left[1-\cos\left(\frac{4\pi nL}{\lambda}+\pi\right)\right]$$

$$L = \frac{\lambda_1\lambda_2}{2n(\lambda_2-\lambda_1)}$$

λ_1 and λ_2 are two adjacent peak wavelength

- ***Characteristic:***
  - *Low cost light source and spectrometer suitable for industry application;*
  - *Wavelength based interrogation technique immune to source fluctuation;*
  - *Short wavelengths allow higher sensitivity for measurement of deflection.*

Conclusion and future work

We experimentally demonstrated the possibility of machining micro-cantilever onto the end of an optical fibre using ps-laser and FIB. The combination of the two machining techniques greatly reduced the machining time while maintaining a good surface quality.

Further study will include an on-line monitoring system for fibre side cantilever which could optimize the 45° angle and maximize the reflection power. In addition, investigation into further data processing to improve resolutions is also planned. Finally, we will try to reduce the surface finish of ps-laser machining and make laser directly machining of a fibre cantilever possible.

Acknowledgement

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Reference

[1] D.Inzz, et. al., "Monolithic fiber-top sensor for critical environments and standard applications", Applied Physics Letters, **88**, 053501 ,2006

Authors contact information: jl294@hw.ac.uk