The Art and Science of Packaging High-Coupling Photonics Devices and Modules

藝術與科學結合之高耦光元件與模組構裝

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Outline

1. Motivation and Review

2. First Generation Microlens

One-Mechanical Torque Control

3. Second Generation Microlens

Two-Electrical Torques Control

4. Third Generation Microlens

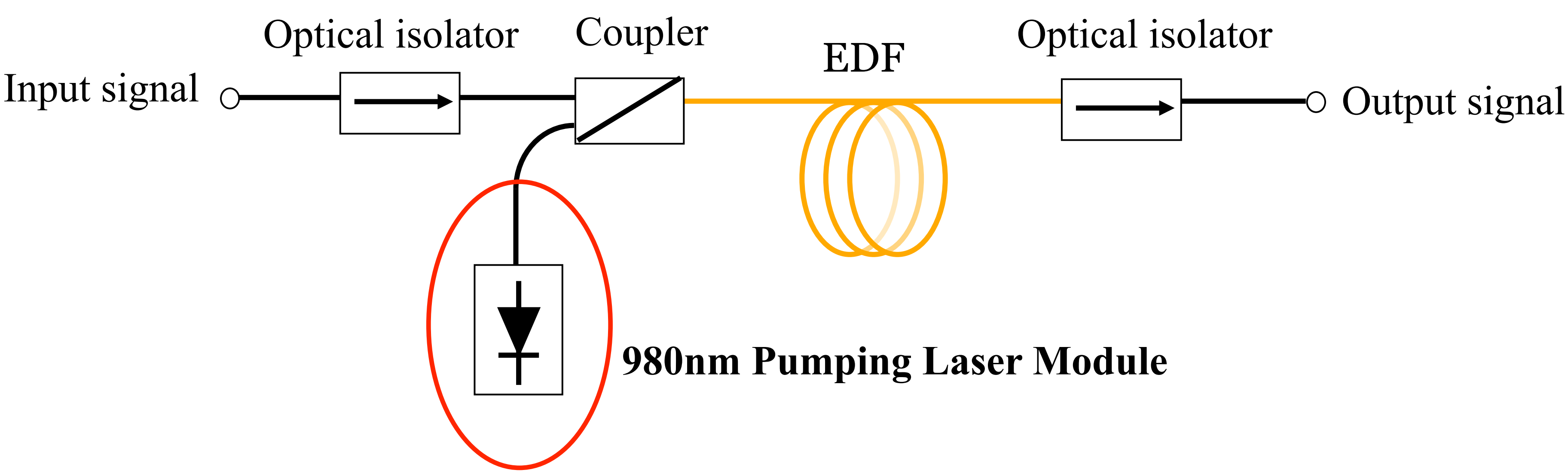
Three-Electrical Torques Control

5. Near-Field Measurements

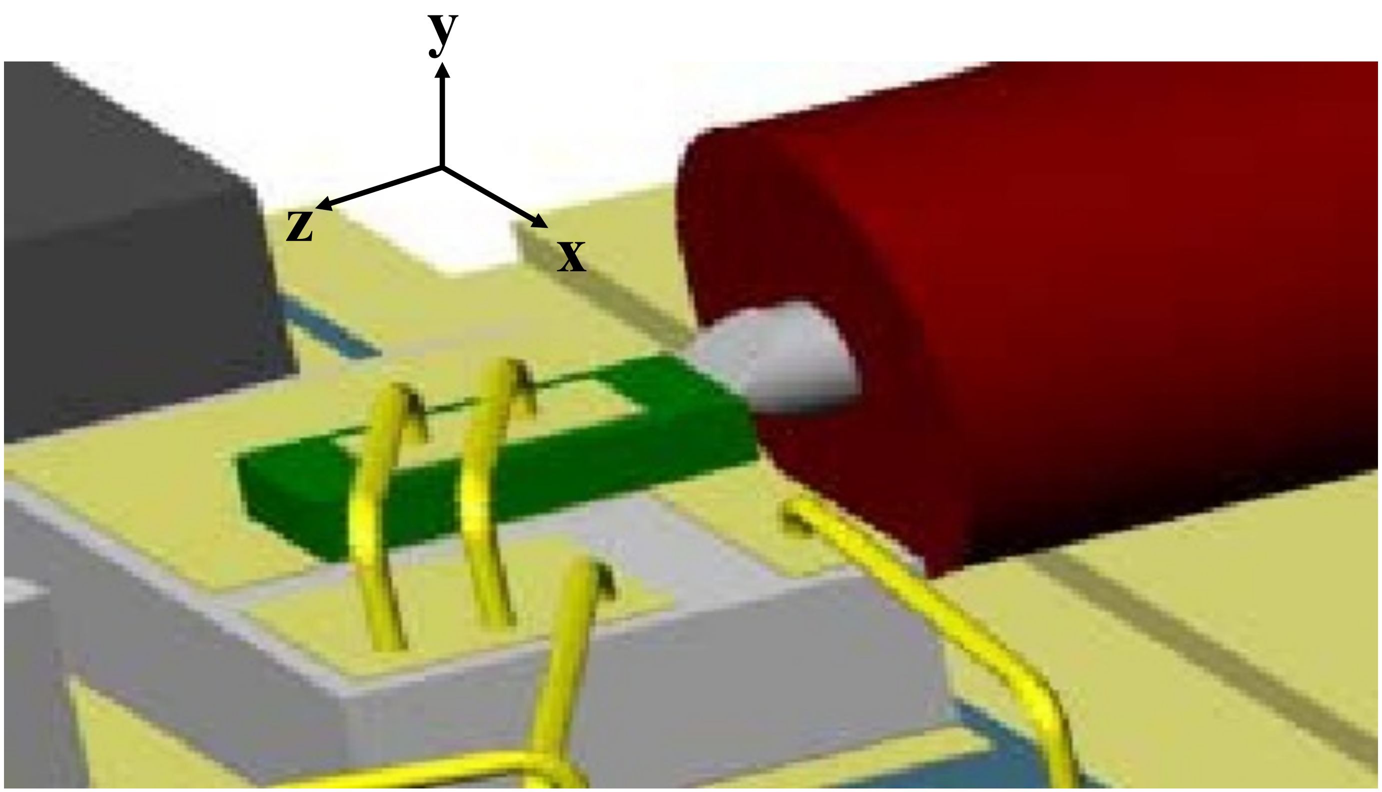
6. Conclusion

EDFA Components

- Erbium-Doped Fiber Amplifier (EDFA)



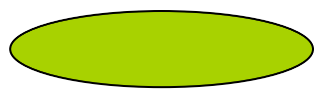
Coupling Setup



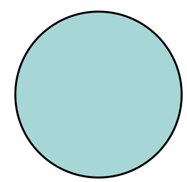
Mode Mismatch

- **980nm Laser**
- **Standard SMF**

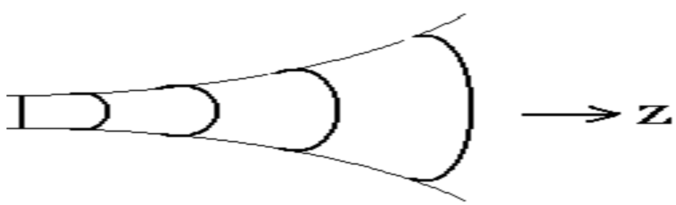
Elliptic Mode Field



Circle Mode Field



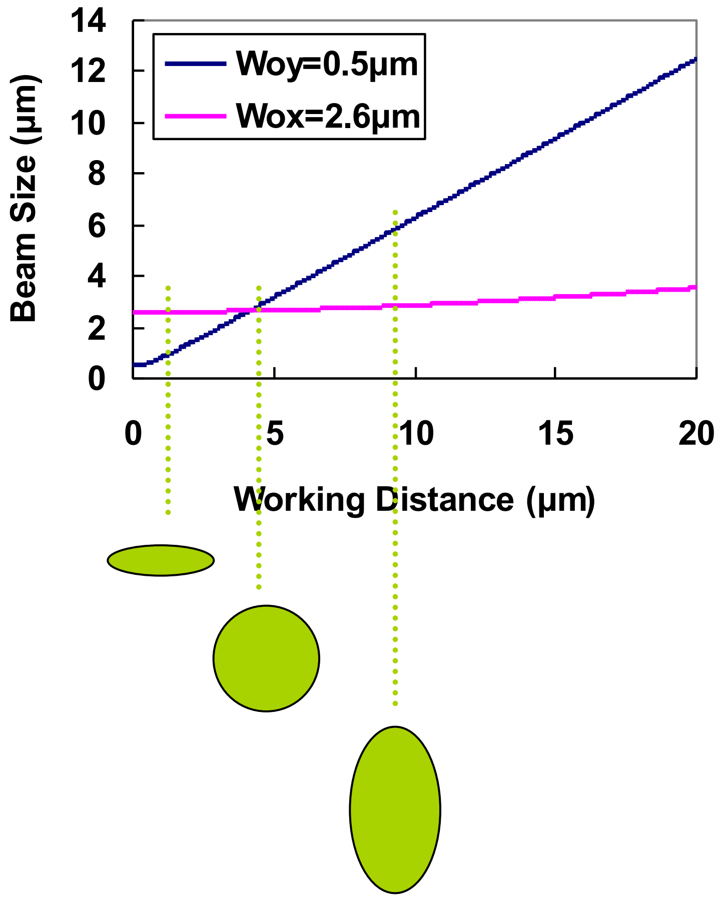
Curved Wavefront



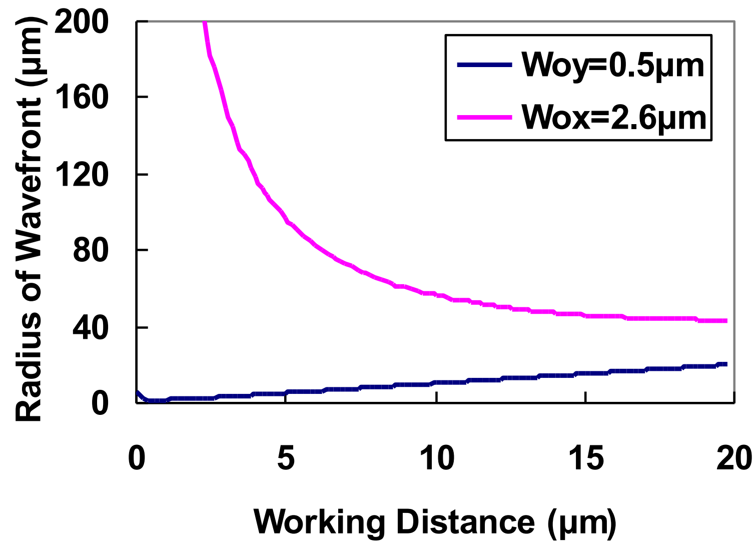
Planar Wavefront

Spot Size and Wavefront in 980-nm Laser

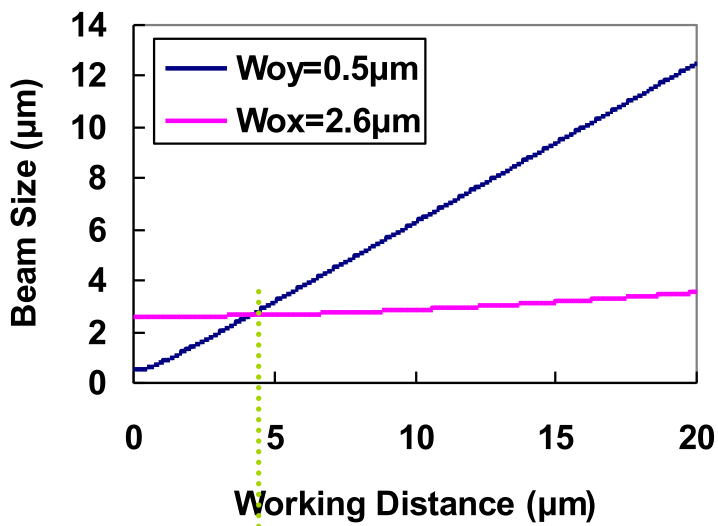
Spot size

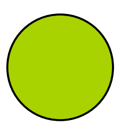


Wavefront



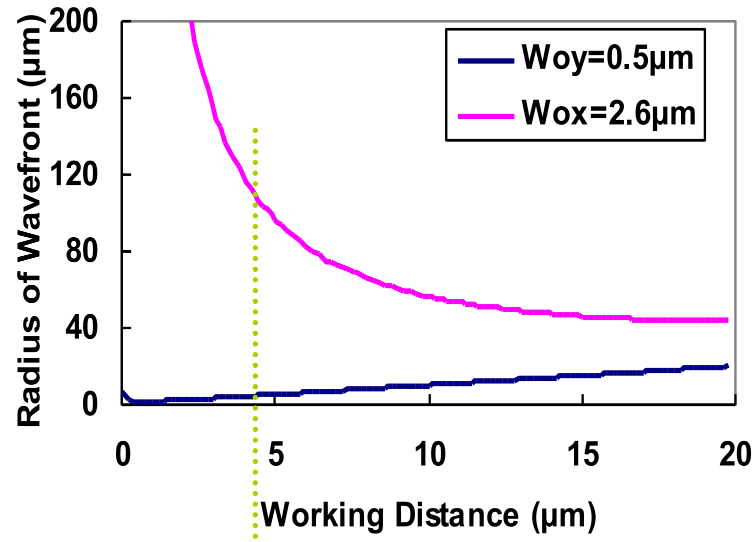
Mode Matching of Microlens Design

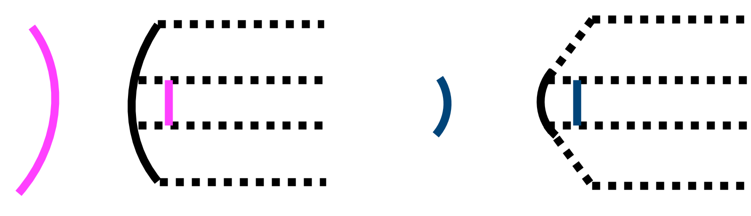




$$\omega_x(z) = \omega_y(z) \sim \omega_f$$

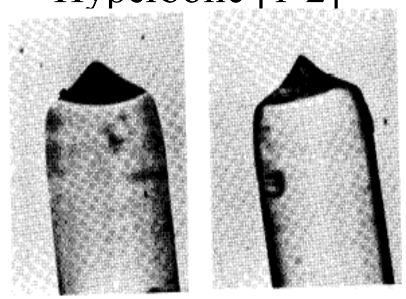
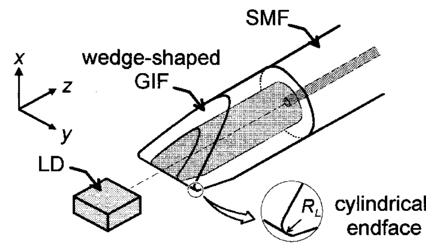
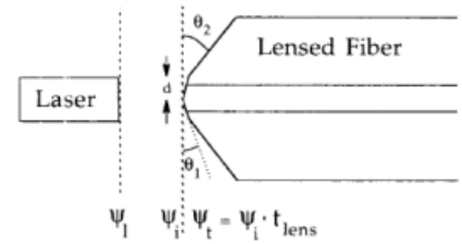
(a) Spot size matching





(b) Wavefront matching

Article Reviews

	Hyperbolic [1-2]	Wedge-shaped GIF [3]	Double Wedge-shaped [4]
Lens shape			
Critical technique	CO_2 Laser processing	Fiber fusion & Fiber polish	Fiber polish
Coupling efficiency	78%	30%	78%
Advantages	High coupling efficiency	High power MM laser	High coupling efficiency
Disadvantages	Expensive equipment Low yield	Complicated process Low reproducibility	Low reproducibility Low yield

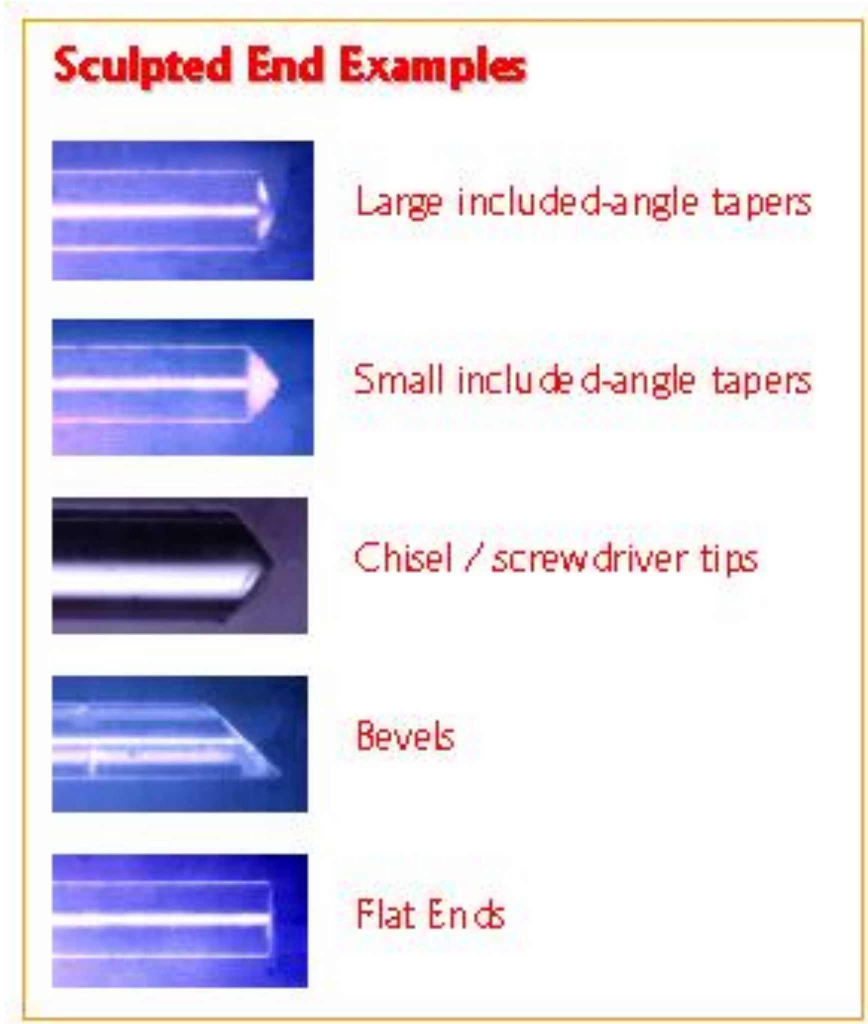
[1]H. M. Presby and C. A. Edwards, "Efficient Coupling of Polarization-Maintaining Fiber to Laser Diodes," IEEE Photonics Technology Letters, Vol. 4, pp. 897-899, 1992.
[2]H. M. Presby and C. R. Giles, "Asymmetric Fiber Microlenses for Efficient Coupling to Elliptical Laser Beams," IEEE Photonics Technology Letters, Vol. 5, pp. 184-186, 1993.
[3]H. Yoda and K. Shiraishi, "A New Scheme of a Lensed Fiber Employing a Wedge-Shaped Graded-Index Fiber Tip for the Coupling Between High-Power Laser Diodes and Single-Mode Fibers," Journal of Lightwave Technology, Vol.19, pp. 1910-1917, 2001.
[4]R. A. Modavis and T. W. Webb, "Anamorphic Microlens for Laser Diode to Single-Mode Fiber Coupling," IEEE Photonics Technology Letters, Vol.7, pp. 798-800, 1995.

Tool of Microlens Fabrication

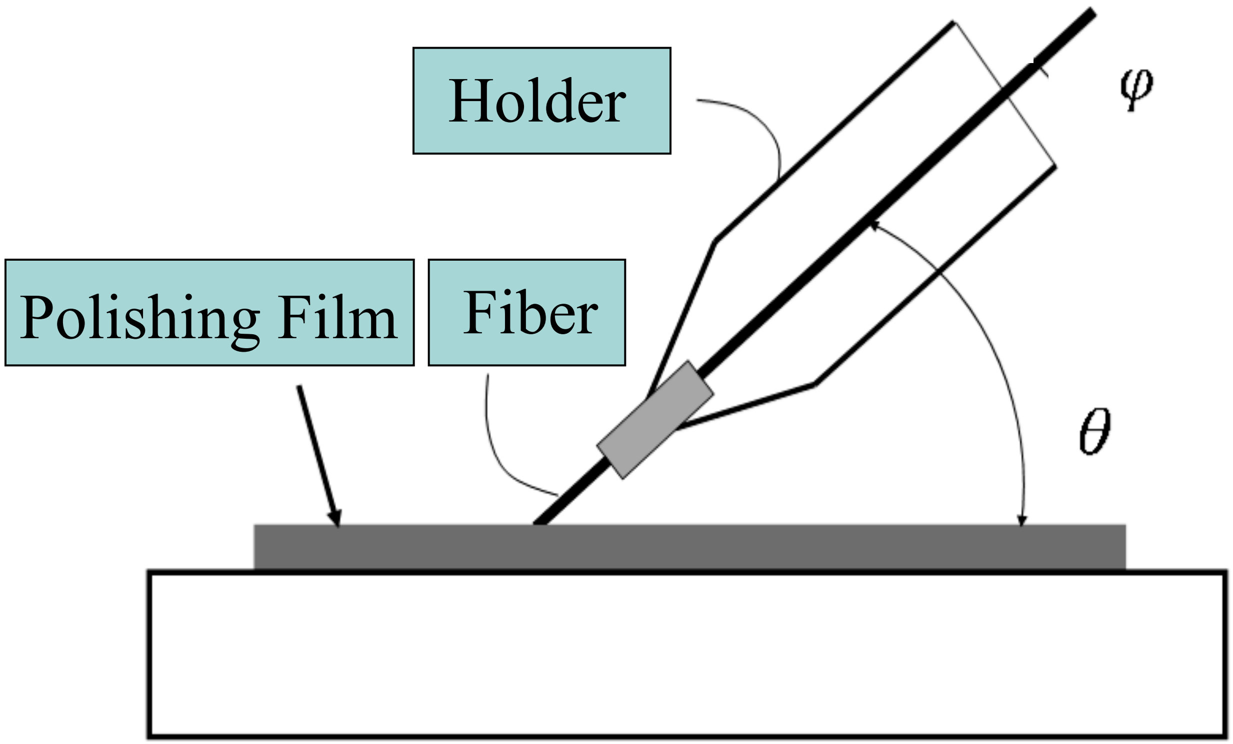
Tool

Ultra Tec (USA)

Microlens

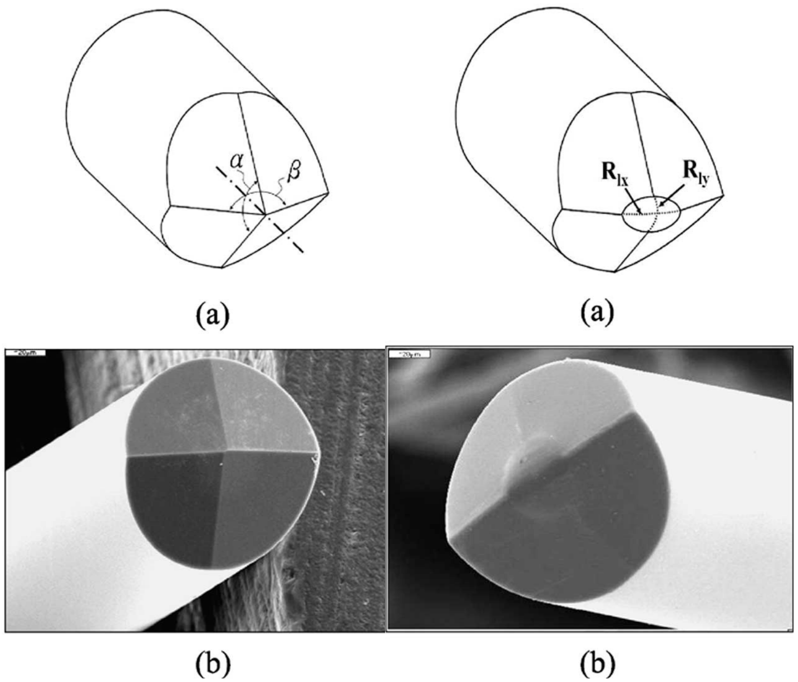


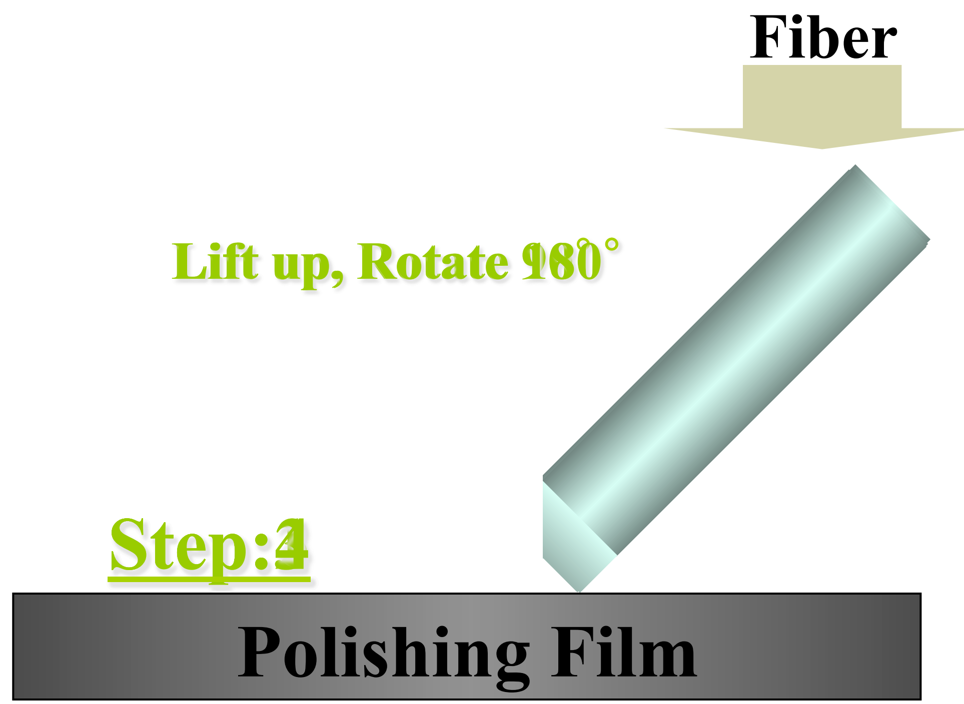
Tool Controlled by two Parameters



θ: Inclination Angle , φ: Rotation Angle

Four-Step Grinding Processes: Quadrangular-Pyramid-Shaped Fiber Endface (QPSFE)





1. Yeh S.M., Lu Y.K., Huang S.Y., Lin H. H., Hsieh C. H., and **Cheng W.H.**, "A Novel Scheme of Lensed Fiber Employing a Quadrangular-Pyramid-Shaped Fiber Endface for Coupling Between High-Power Laser Diodes and Single-Mode Fibers," Journal of Lightwave Technology, 22, 1374.(2004)

Components

- Laser Chips

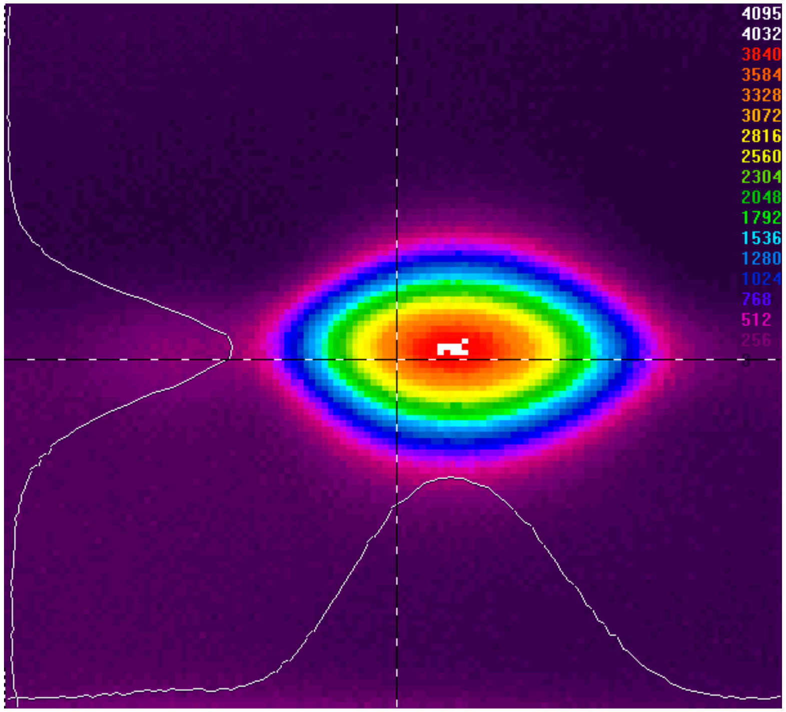
  Divergence Angles = 8° X 40° (aspect ratio: 1:5)

  (W_{xo}= 2.6μm, W_{yo}= 0.5μm)

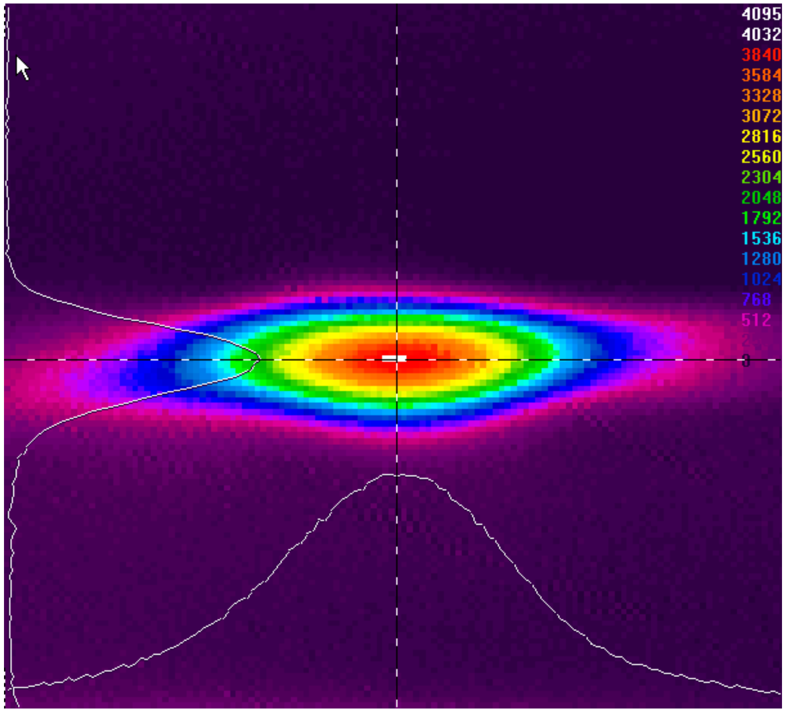
- SMFs

  MFD_1 = 4.0μm, MFD_2 = 5.7μm

Far-Field Pattern of QPSFE



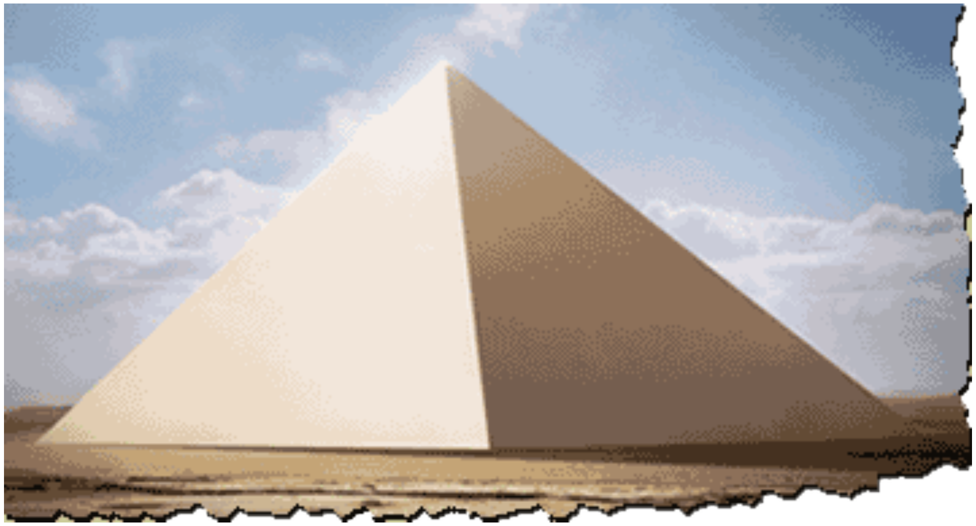
Aspect Ratio = 1 : 2.4
(η = 44 %)



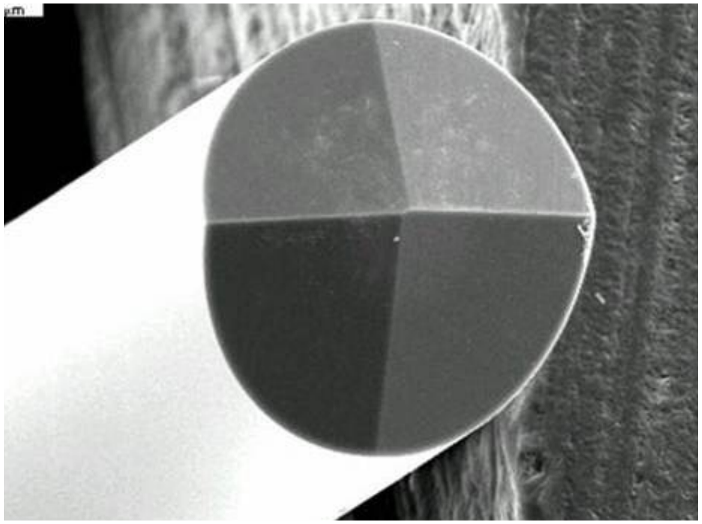
Aspect Ratio = 1 : 3.9
(η= 83 %)

Pyramid

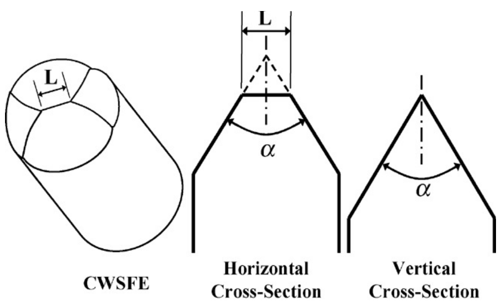
The Pyramids of Egypt



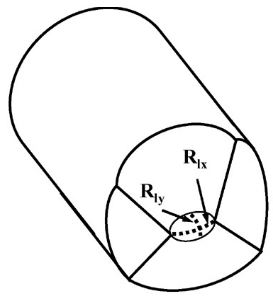
QPSFE
Quadrangular-
Pyramid-Shaped
Fiber Endface



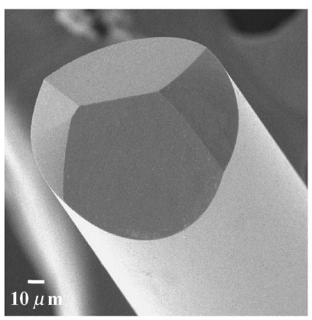
Three-Step Grinding Process: Conical-Wedge-Shaped Fiber Endface (CWSFE)



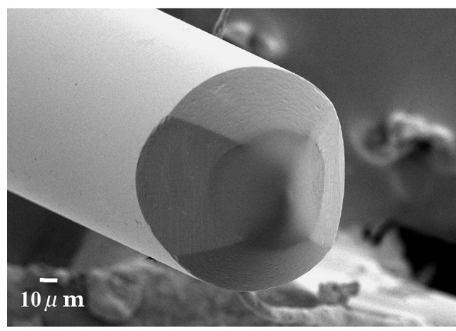
(a)



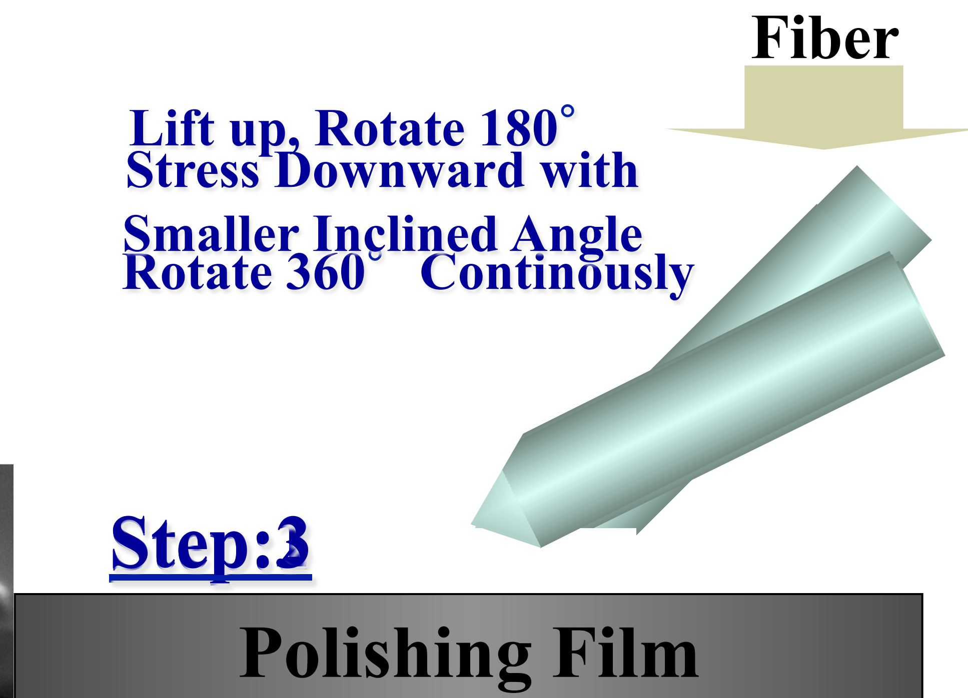
(a)



(b)

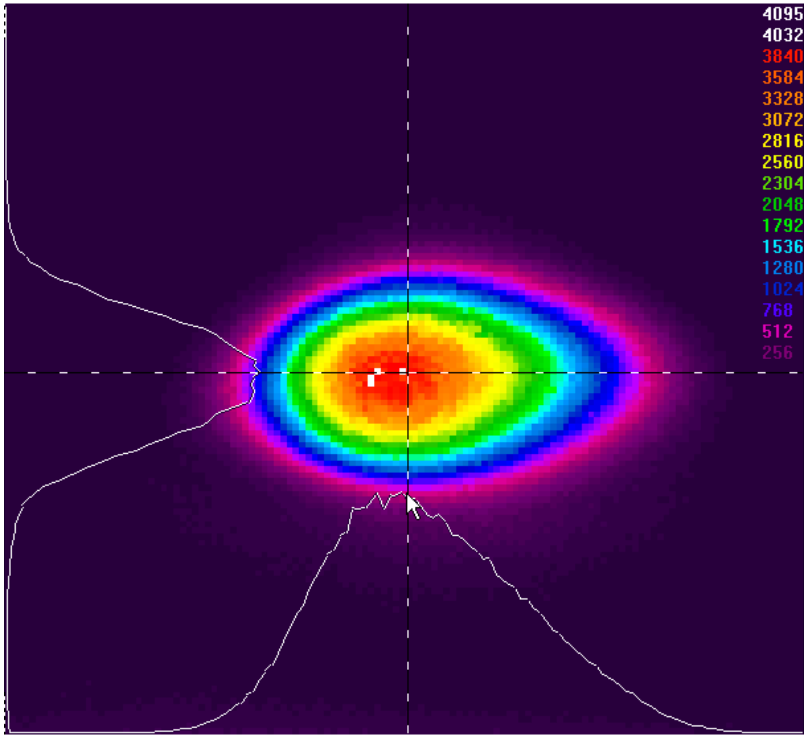


(b)

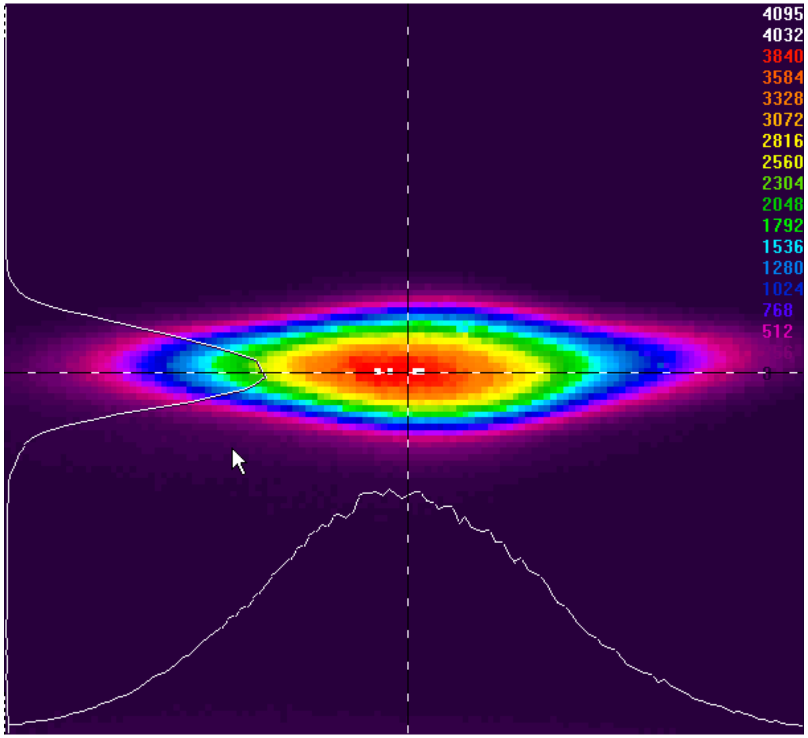


1. Yeh S. M., Huang S. Y. and **Cheng W. H.**, "A new scheme of conical-wedge-shaped fiber endface for coupling between high-power laser diodes and single-mode fibers," Journal of Lightwave Technology, 23, 1781.(2005).
2.US patent7515789 (2009)，7295729 (2007)，Conical-wedge-shaped lensed fiber and the method of making the same

Far-Field Pattern of CWSFE

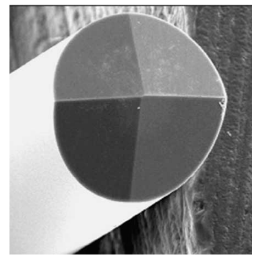
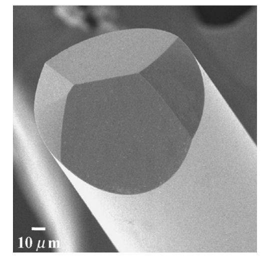


Aspect Ratio = 1 : 1.7
(η = 61 %)



Aspect Ratio = 1 : 3.8
(η= 84 %)

Comparison Structures of QPSFE and CWSFE

	QPSFE	CWSFE
Shape		
Grinding step	4	3
Range/average offset (μm)	2.3/1.5	1.2/0.9
Max. Coupling Efficiency	83%	84%
Advantage	High coupling efficiency.	High coupling efficiency, Less grinding step.
Disadvantage	Low yield due to multi-step grinding processes, requires fusing process.	Low yield due to multi-step grinding processes, requires fusing process.

Outline

1. **Motivation and Review**
2. **First Generation Microlens**
   One-Mechanical Torque Control
3. **Second Generation Microlens**
   Two-Electrical Torques Control
4. **Third Generation Microlens**
   Three-Electrical Torques Control
5. **Near-Field Measurements**
6. **Conclusion**

Single-Step Grinding Technique

First generation of microlens (G1)

One-mechanical torque control incline angle (θ) and rotation angle (ϕ).

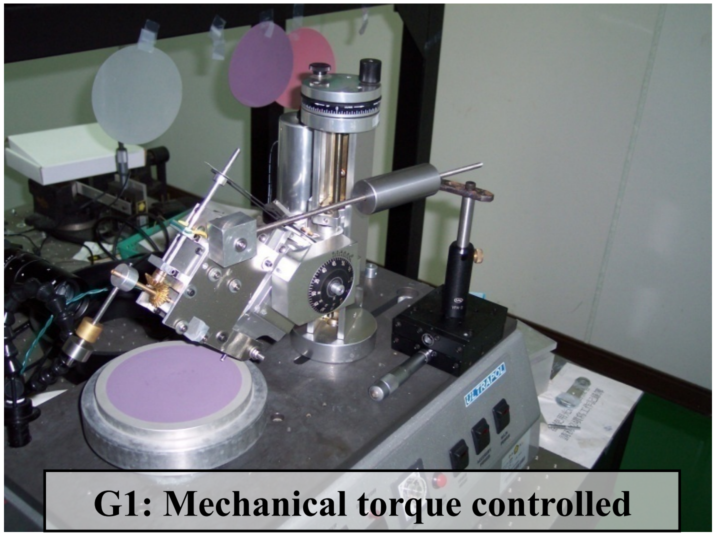
Second generation of microlens (G2)

Two-electrical torques control incline angle (θ) and rotation angle (ϕ).

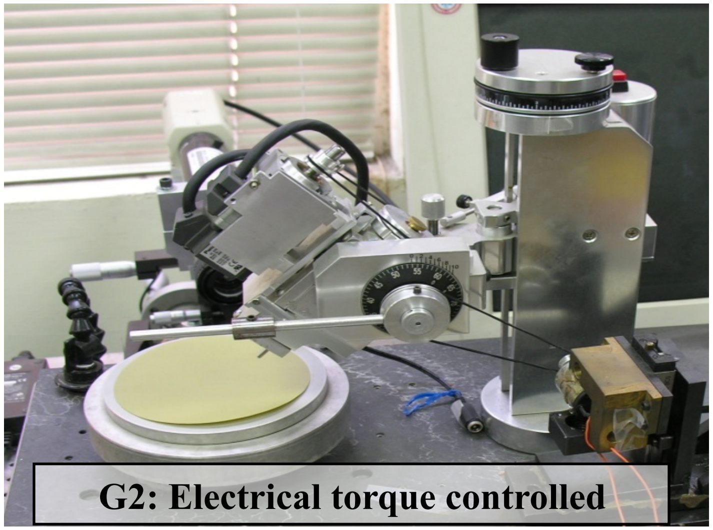
Third generation of microlens (G3)

Three-electrical torques control incline angle (θ), rotation angle (ϕ), and contact height (H).

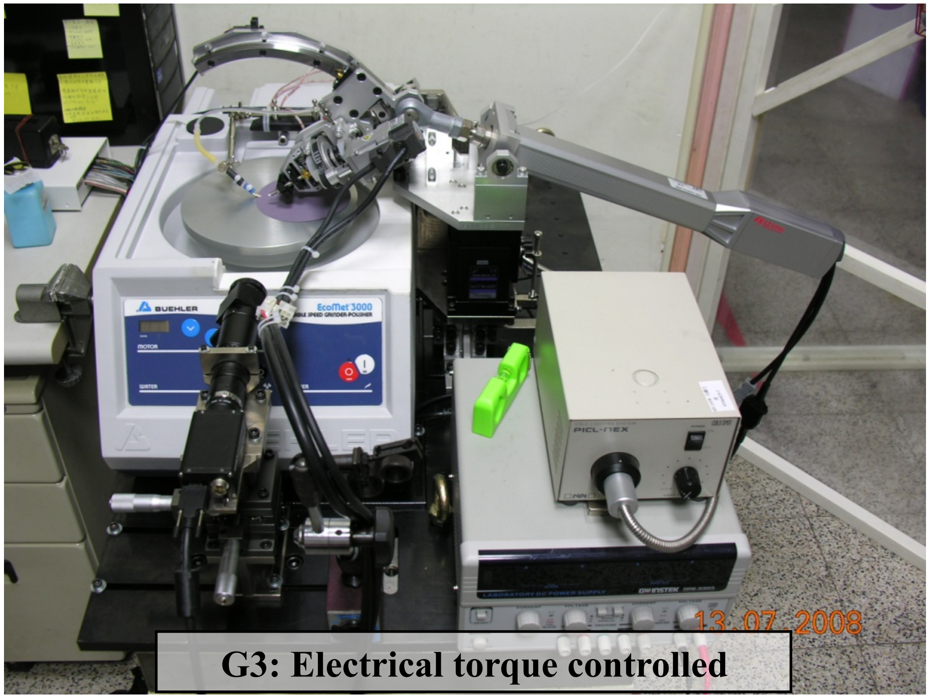
Tool of Single-Step Grinding Process



G1: Mechanical torque controlled



G2: Electrical torque controlled



G3: Electrical torque controlled

Formation Principle of Asymmetric Endface

- According to Preston's equation, the material removal rate (dT/dt) can be represented as:

$$\frac{dT}{dt} = K\frac{N}{A}\frac{dS}{dt}$$

- $\frac{dT}{dt} = R$ (Material Removal Rate)

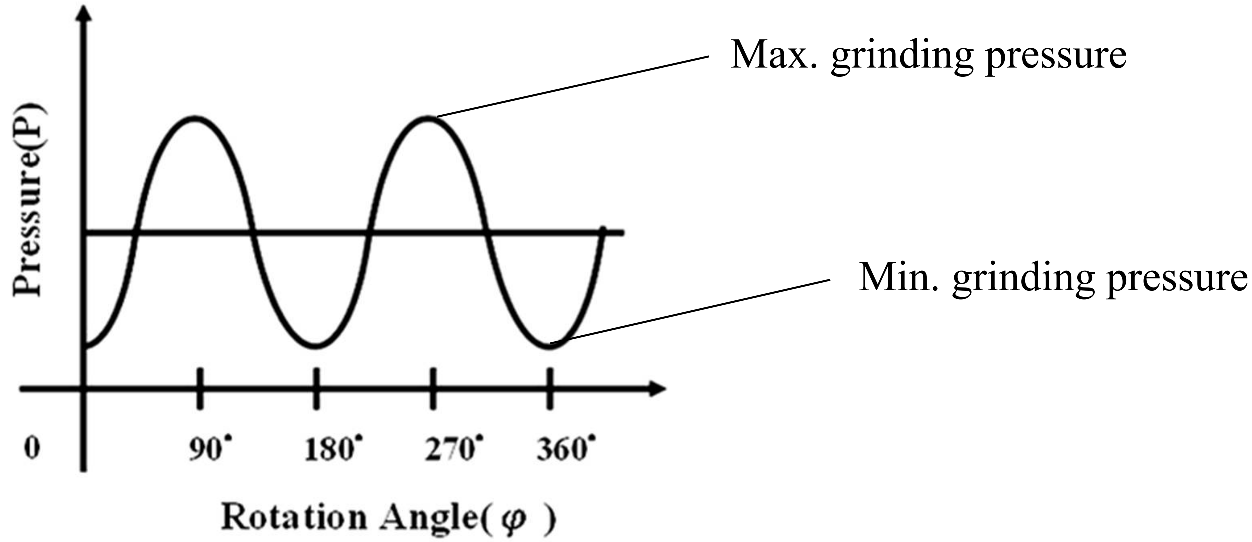
- $\frac{N}{A} = P$ (Normal Pressure)

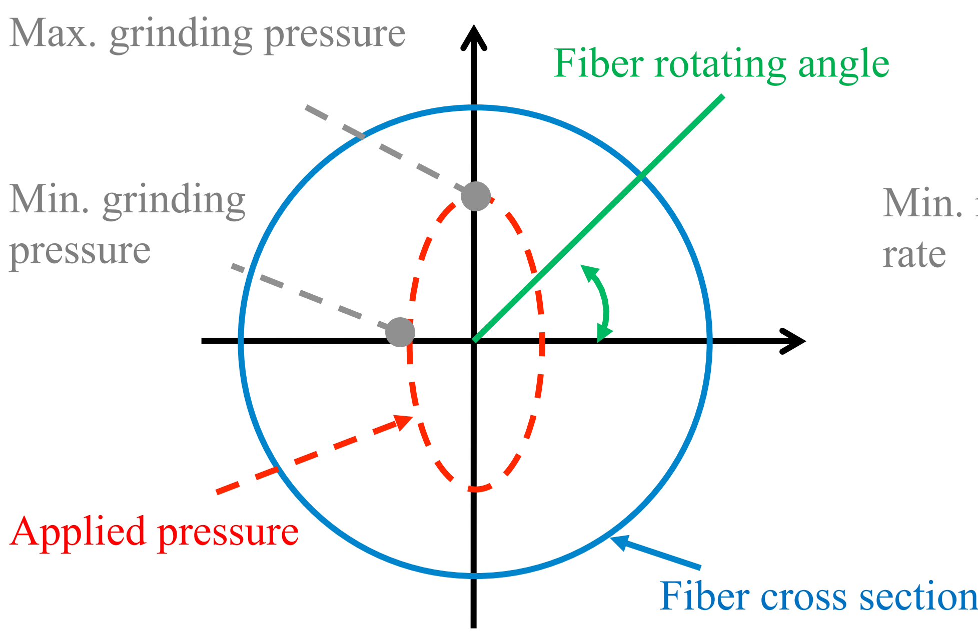
- $\frac{dS}{dt} = V$ (Relative Velocity)

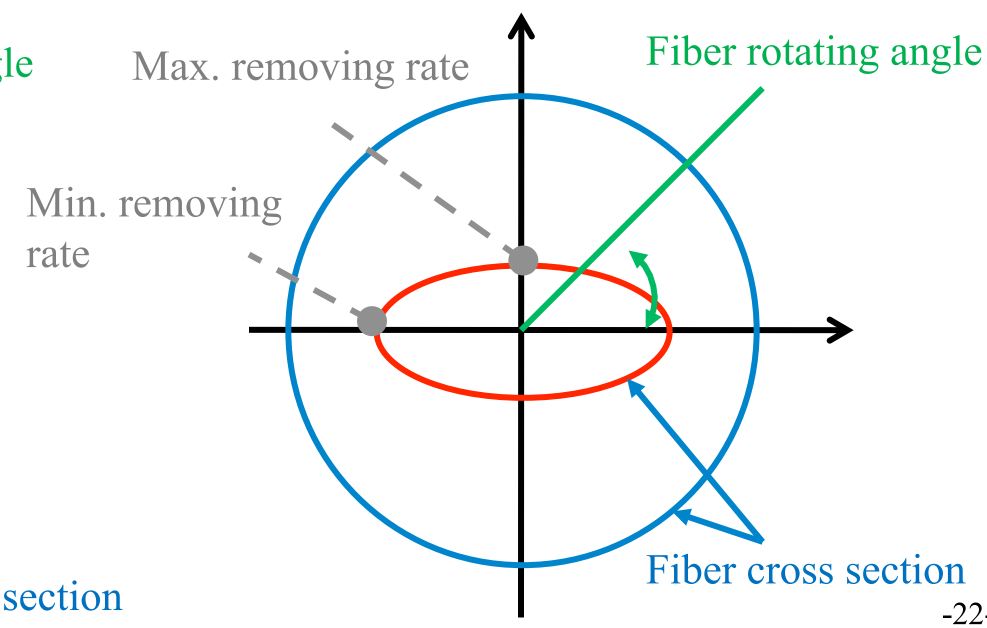
$$R = KPV$$

F. W. Preston, "The theory and design of plate glass polishing machines," Journal of the Society of Glass Technology, Vol. 11, pp. 214-256, 1927.

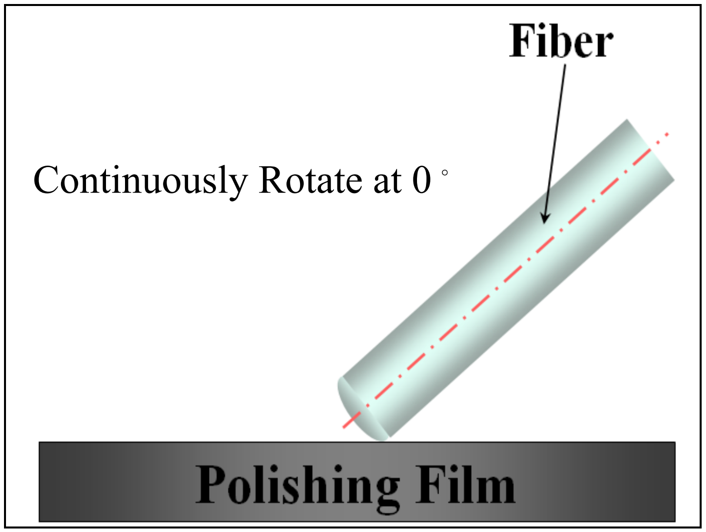
Formation of Asymmetric Fiber Endface

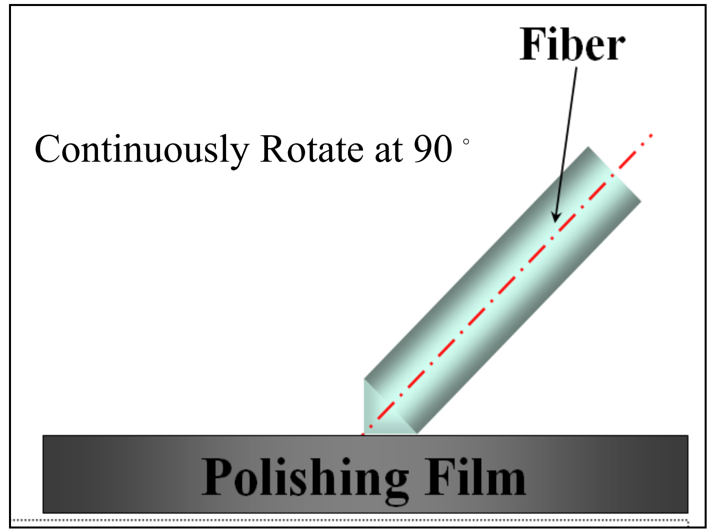


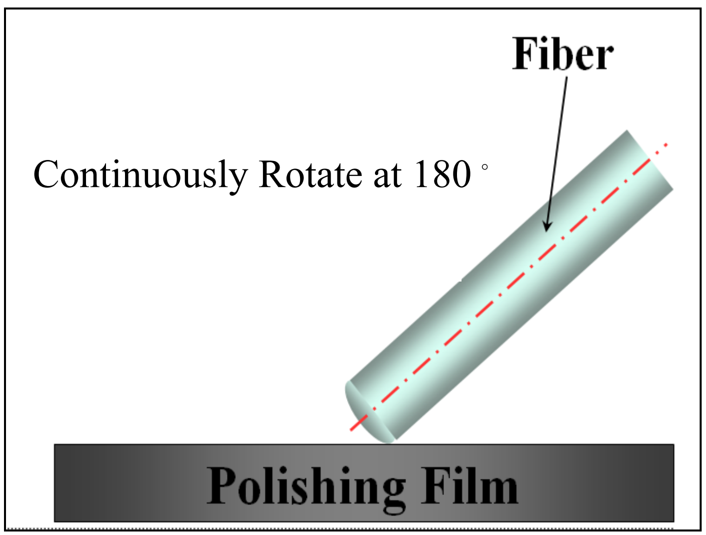


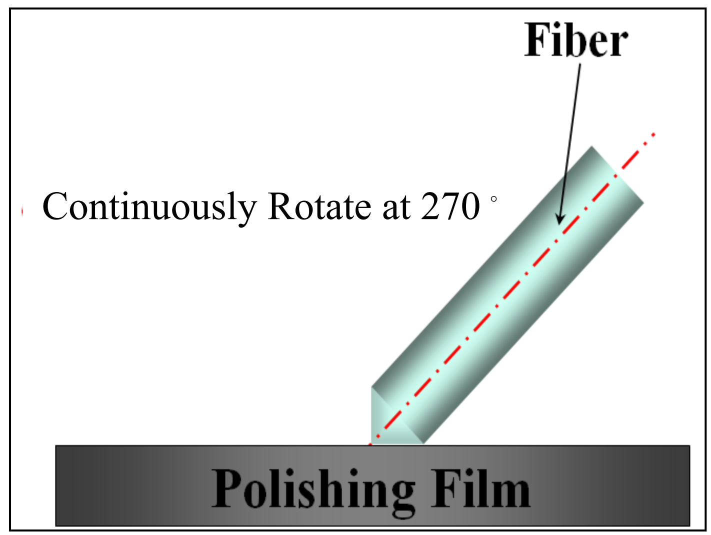


GI: One-Mechanical Torque Controlled



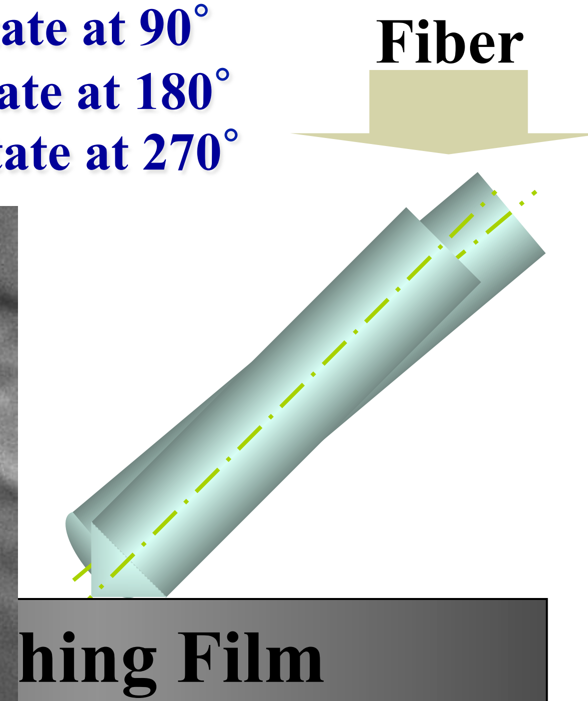


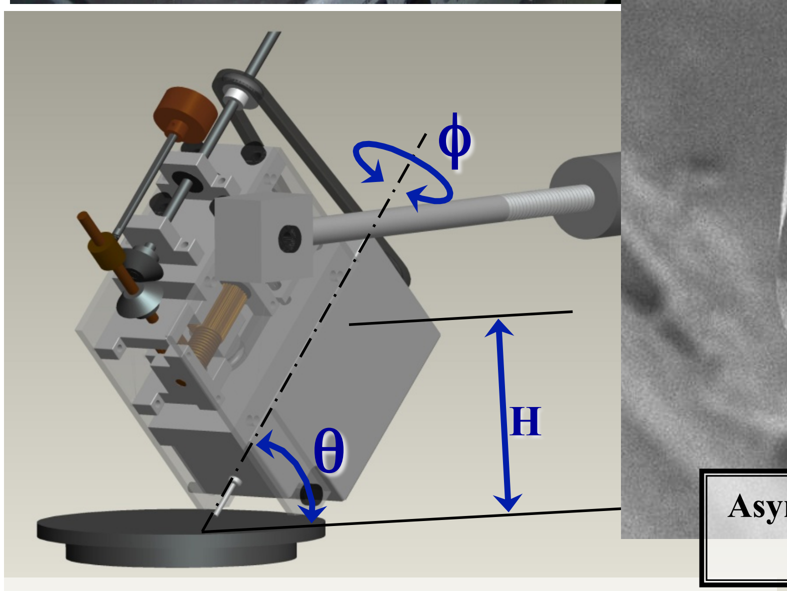


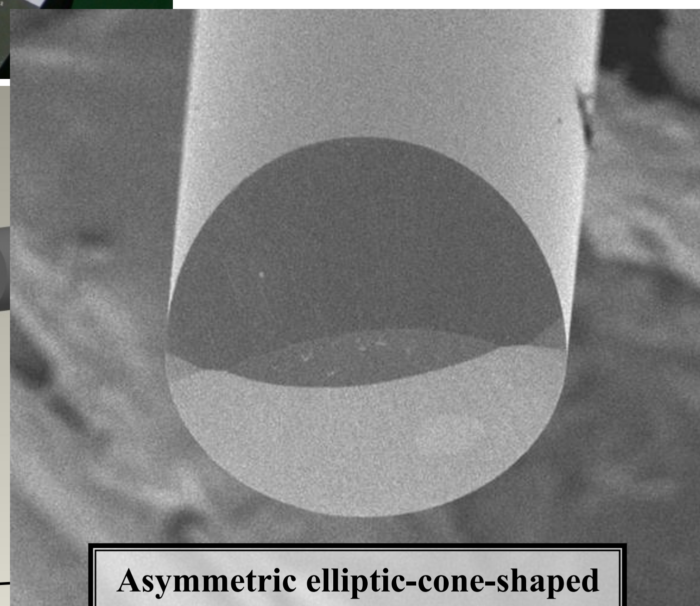


G1 – One-Mechanical Torque Controlled (AECSFE)

Continuously Rotate at 0°
Continuously Rotate at 90°
Continuously Rotate at 180°
Continuously Rotate at 270°





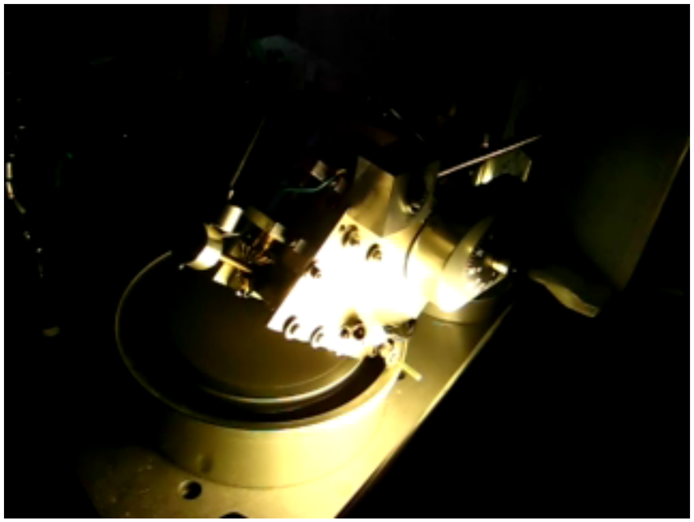


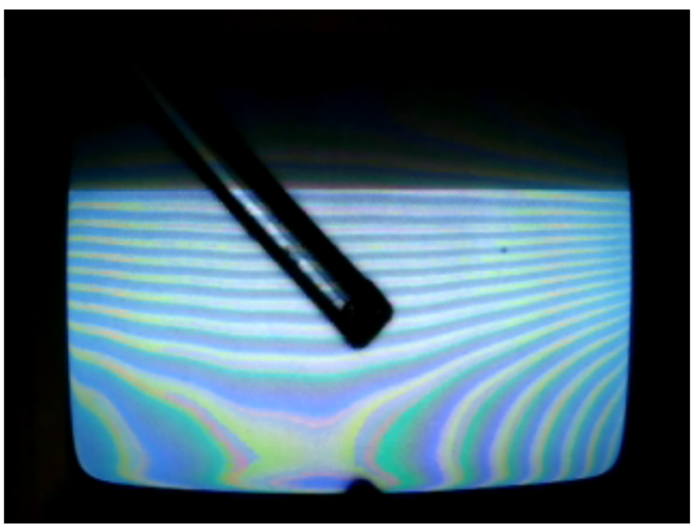
Asymmetric elliptic-cone-shaped fiber endface (AECSFE)

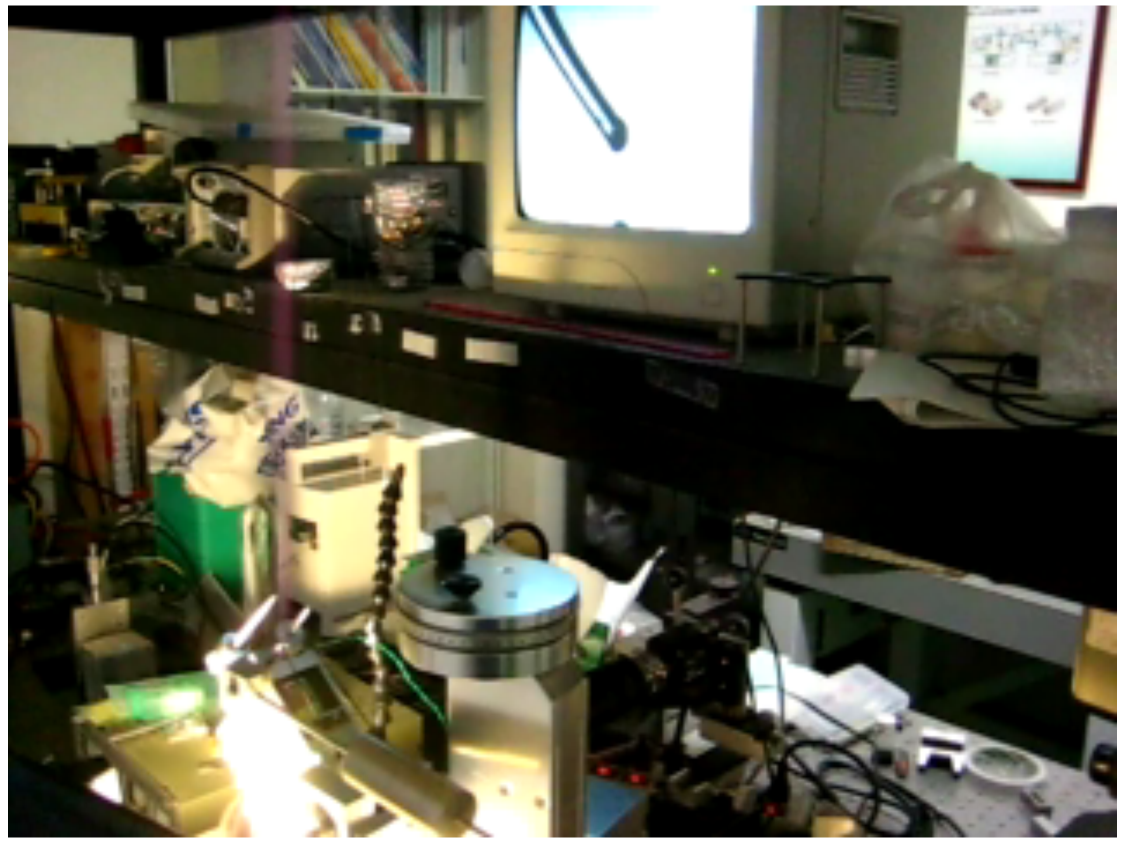
ϕ variable (H & θ dependent on ϕ)

1. Yu-Kuan Lu, Ying-Chien Tsai, Yu-Da Liu, Szu-Ming Yeh, Chi-Chung Lin, and **Wood-Hi Cheng**, "Asymmetric elliptic cone-shaped microlens for efficient coupling to high-power laser diodes," Optics Express, 15, 1434 (2007).
2. US patent：7494399，Single-step fiber grinding process and apparatus

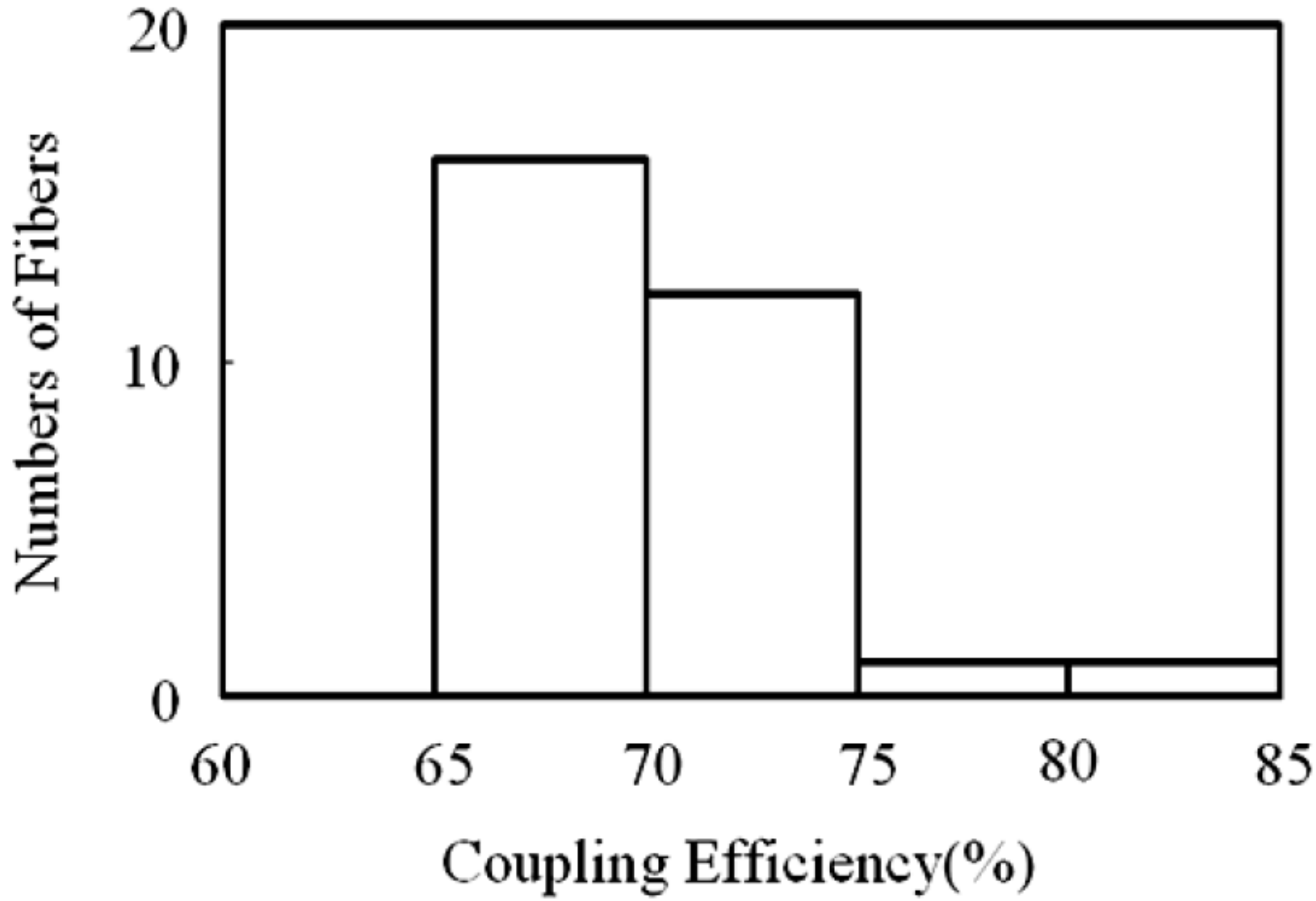
G1 – One-Mechanical Torque Controlled AECSFE Fabrication





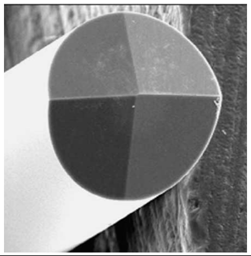
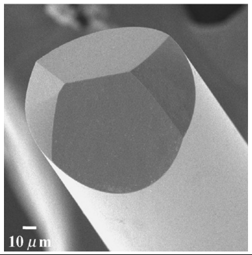
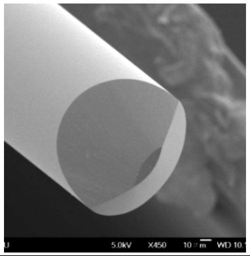


Histogram of measured coupling efficiencies between 980-nm laser diode and AECSFE



Average coupling efficiency = 71%

Comparison Structures of Asymmetric Fiber Endface (QPSFE, CWSFE, AESFE)

	QPSFE	CWSFE	AECSFE
Shape			
Grinding step	4	3	1
Range/average offset (μm)	2.3/1.5	1.2/0.9	0.8/0.4
Max Coupling Efficiency	83%	84%	85%
Advantage	High coupling efficiency.	High coupling efficiency.	Single-step grinding technique. High yield and high coupling efficiency.
Disadvantage	Low yield due to multi-step grinding processes	Low yield due to multi-step grinding processes.	Low aspect ratio.

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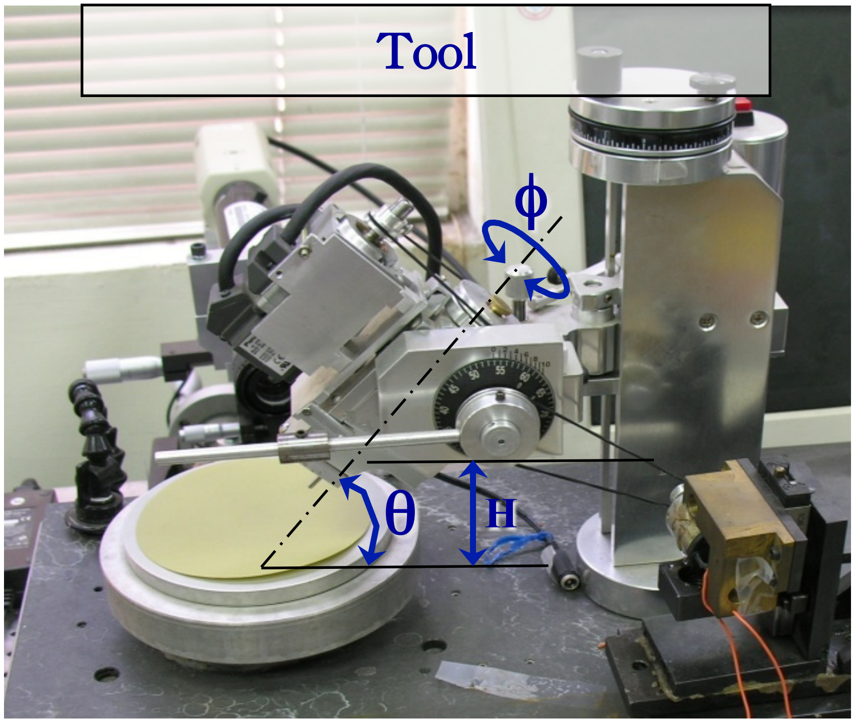
G2 – Two-Electrical Torque Controlled

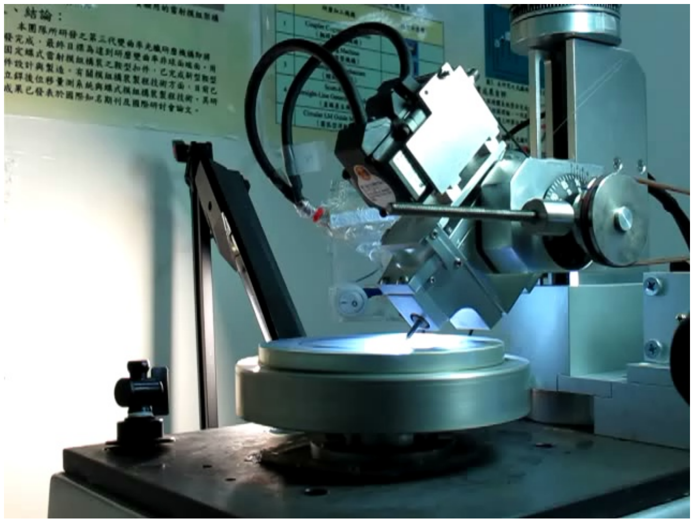


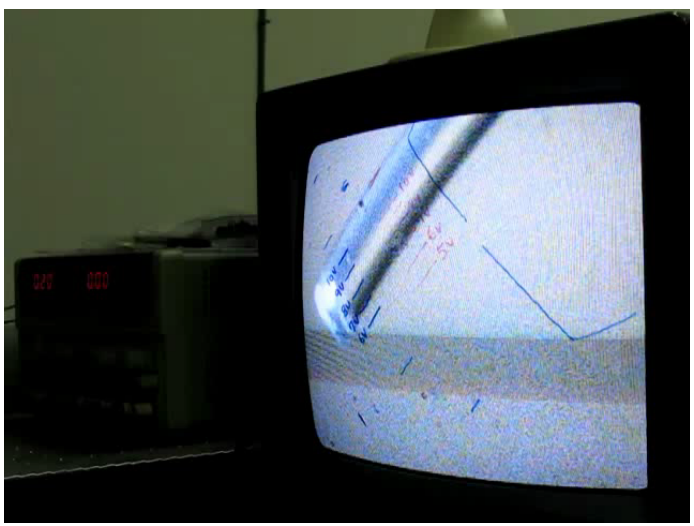
Advantages：
1. Curvature with high aspect ratio
2. Different shapes of endface

H constant, θ & φ variables

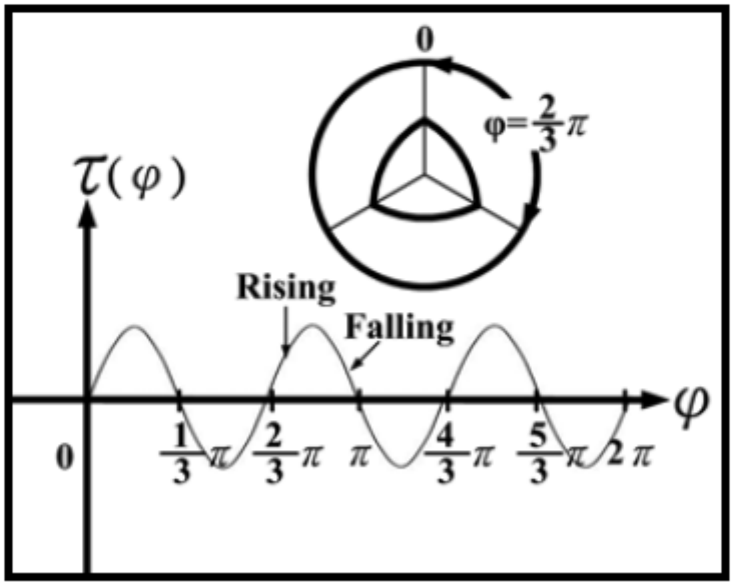
1. Tsai Y.C., Liu Y.D., Cao C.L., Lu Y.K. and **Cheng W.H.**, "A new scheme of fiber end-face fabrication employing a variable torque technique," Journal of Micromechanics and Microengineering, 18, 055003.1-055003.7. (2008)

G2 – Two-Electrical Torques Controlled



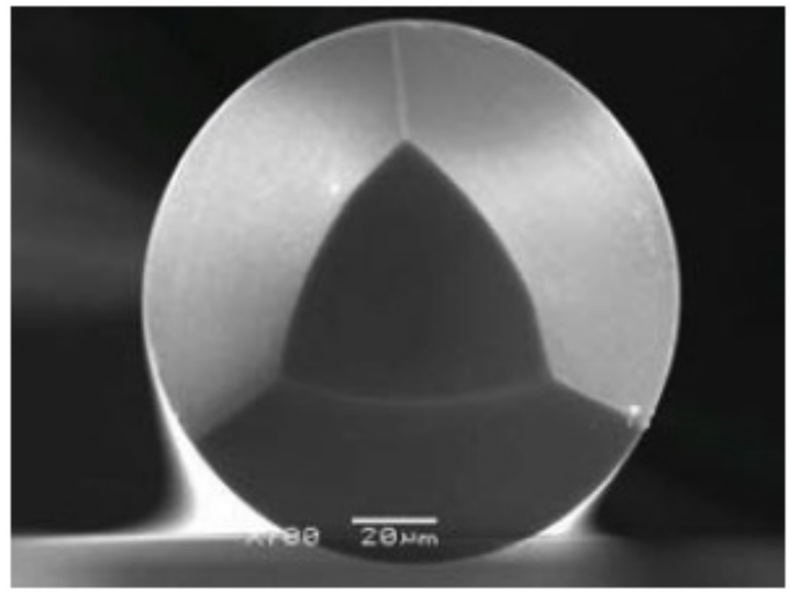


Torque Application of the Sinusoidal Wave Input and its Endface Output



(a)

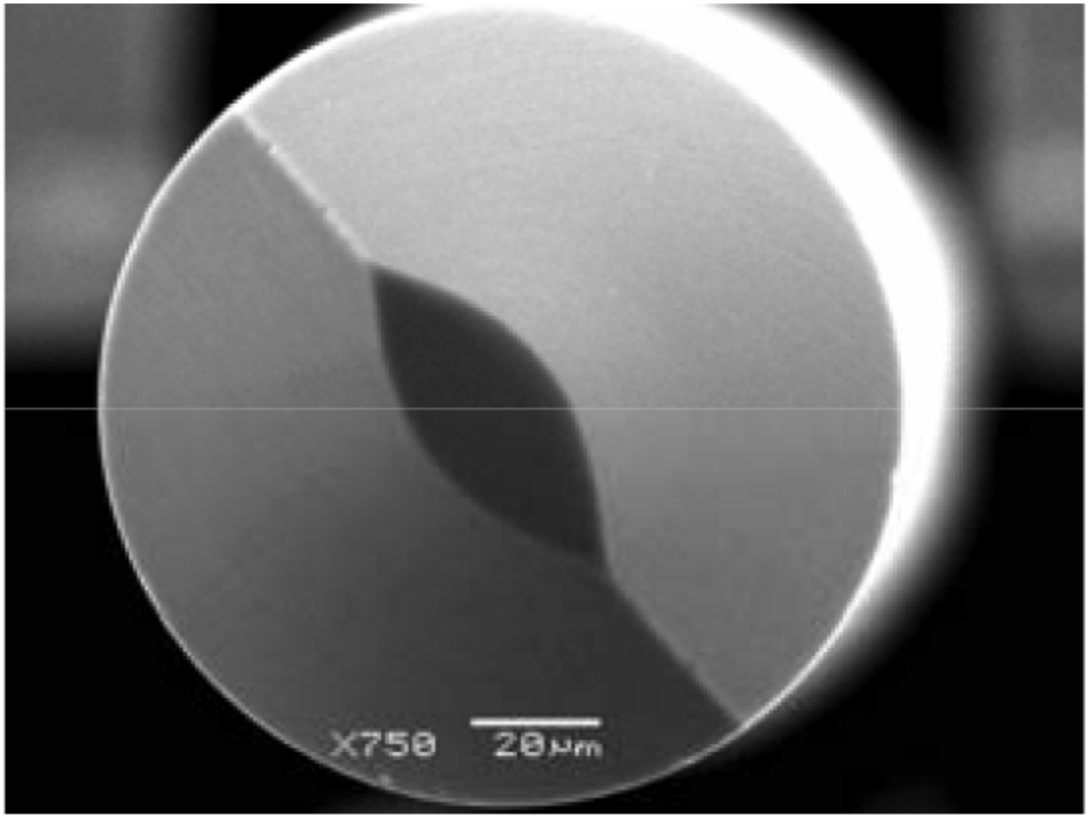
Relationship between the torque and its excepted end-face.



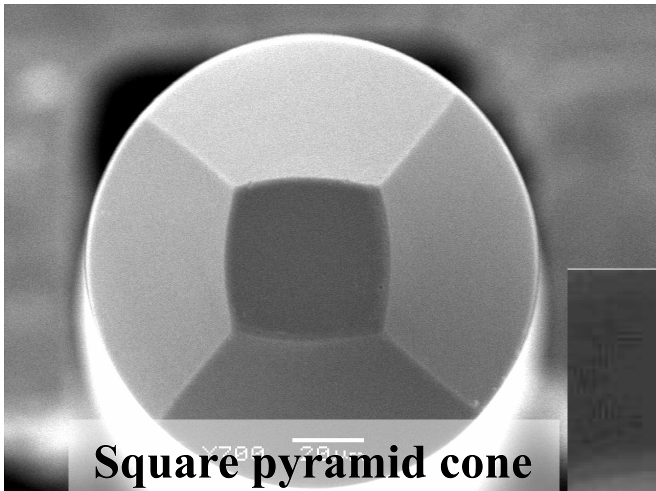
(b)

SEM of the finished model.

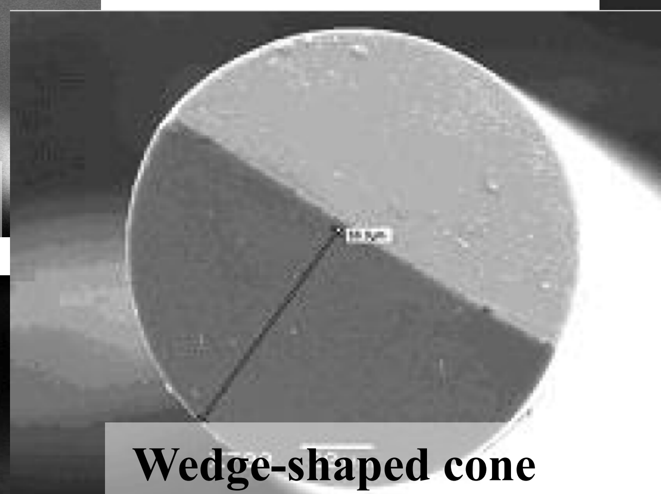
Asymmetric Elliptic-Cone-Shaped Microlens (AECSM)



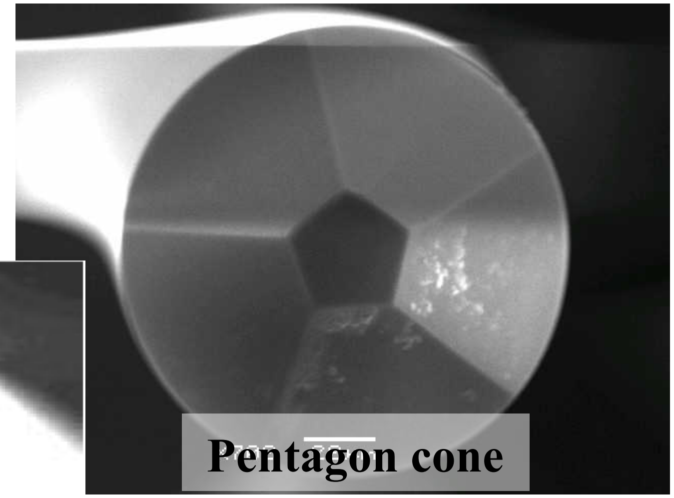
Different Shapes of Endface (Artwork Microlens)



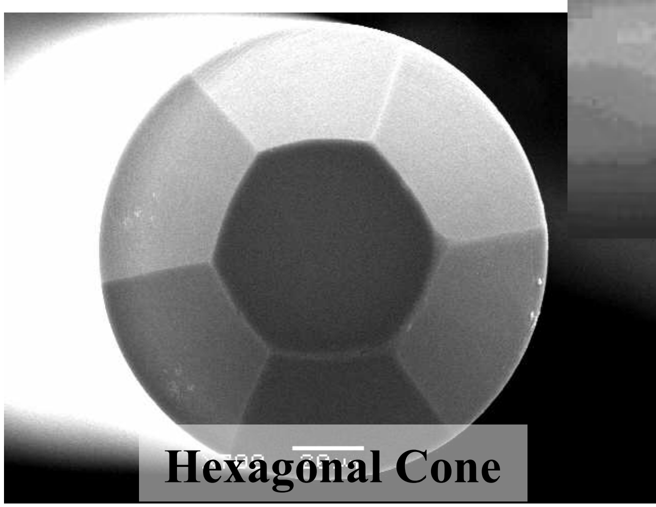
Square pyramid cone



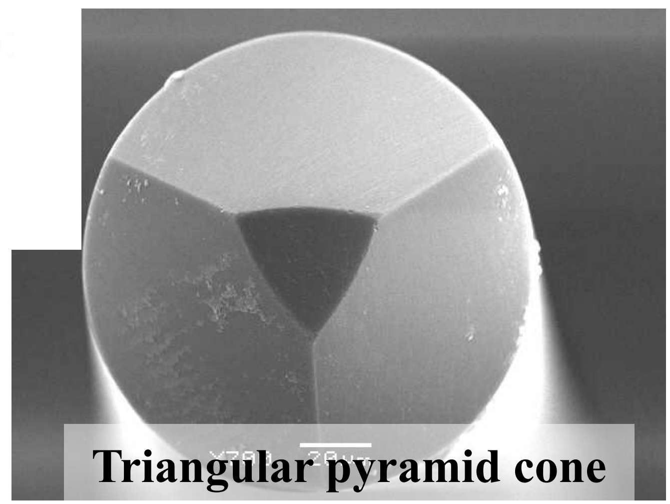
Wedge-shaped cone



Pentagon cone



Hexagonal Cone



Triangular pyramid cone

Outline

1. Motivation and Review

2. First Generation Microlens

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4. Third Generation Microlens

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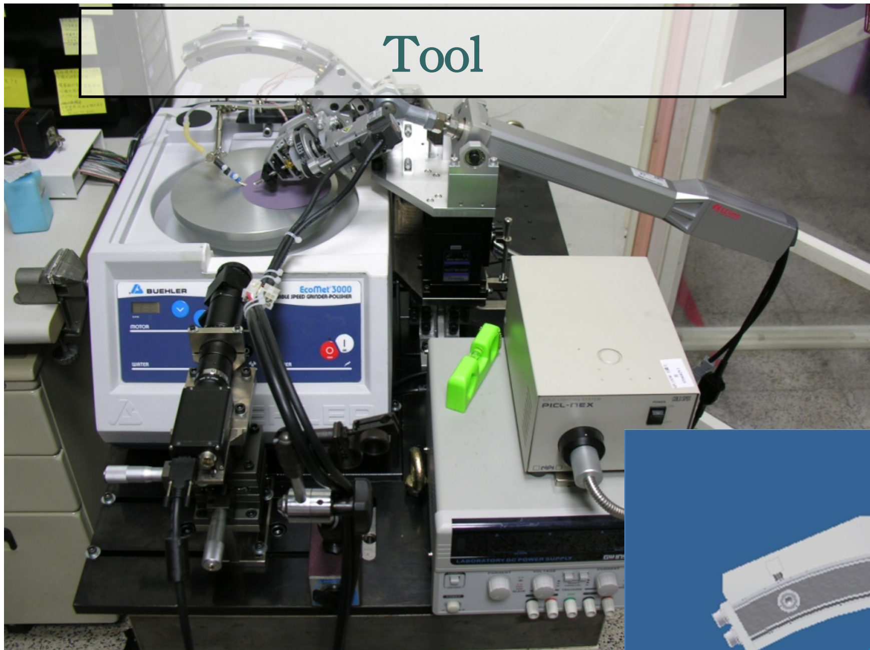
5. Near-Field Measurements

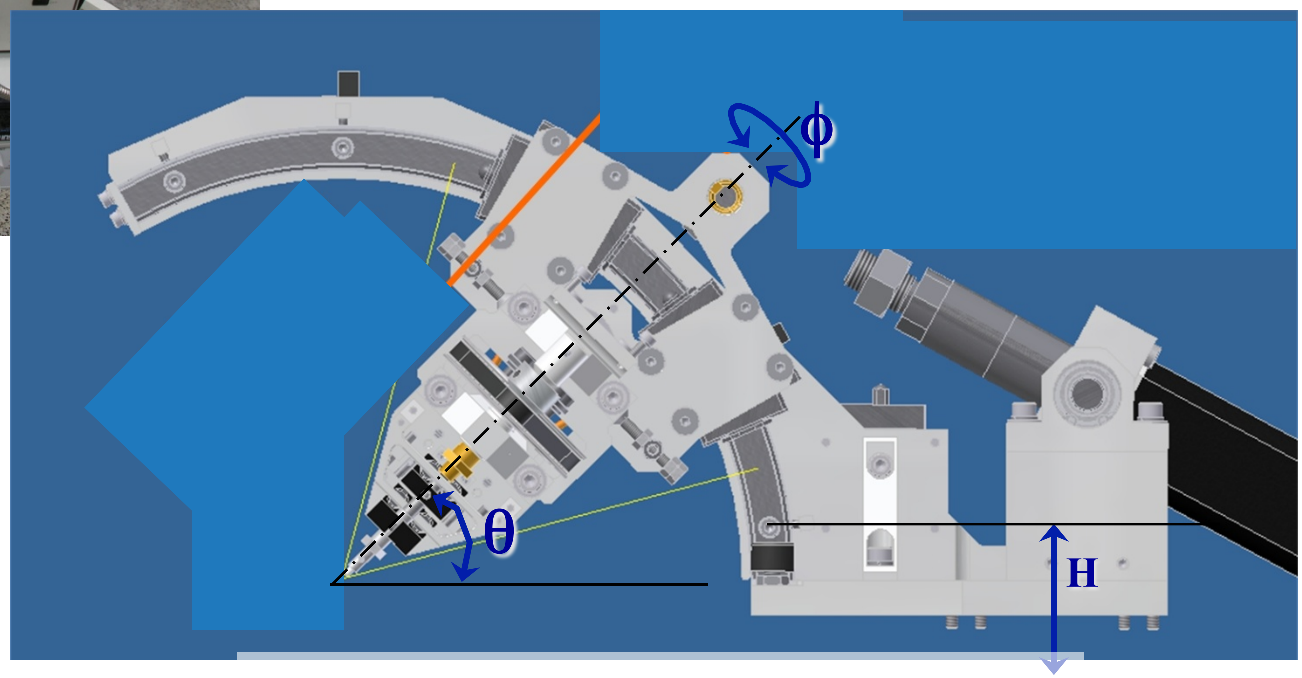
6. Conclusion

G3 – Three-Electrical Torques Controlled



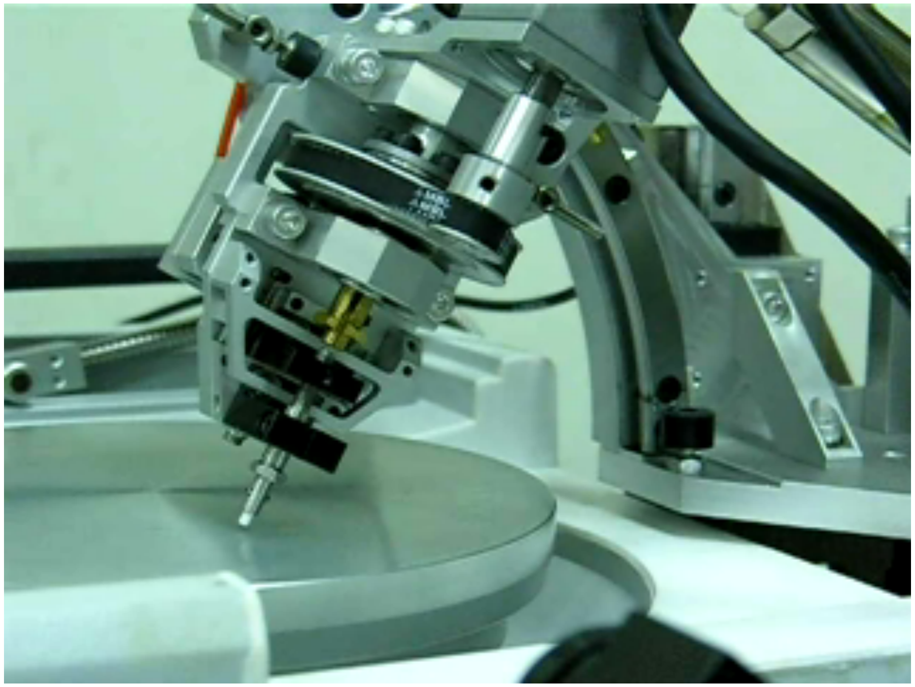
Three-electrical torques controlled incline angle (θ), rotation angle (ϕ), and contact height (H)

Advantage: Double-variable-curvature microlens Curvature. Fusion process applied only for fine polishing (not reshape).

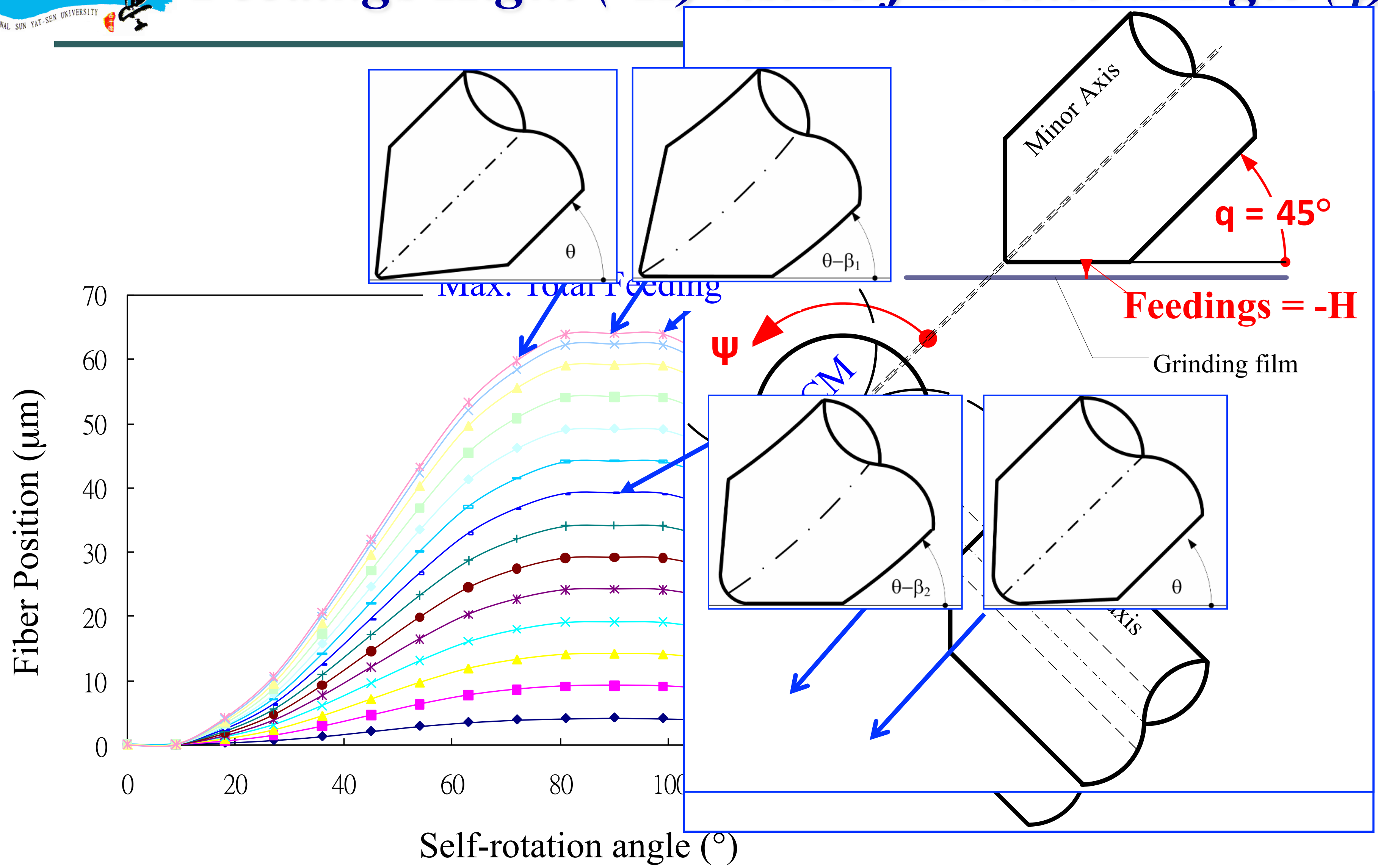


H, θ & ϕ independent variables

G3 – Three-Electrical Torques Controlled

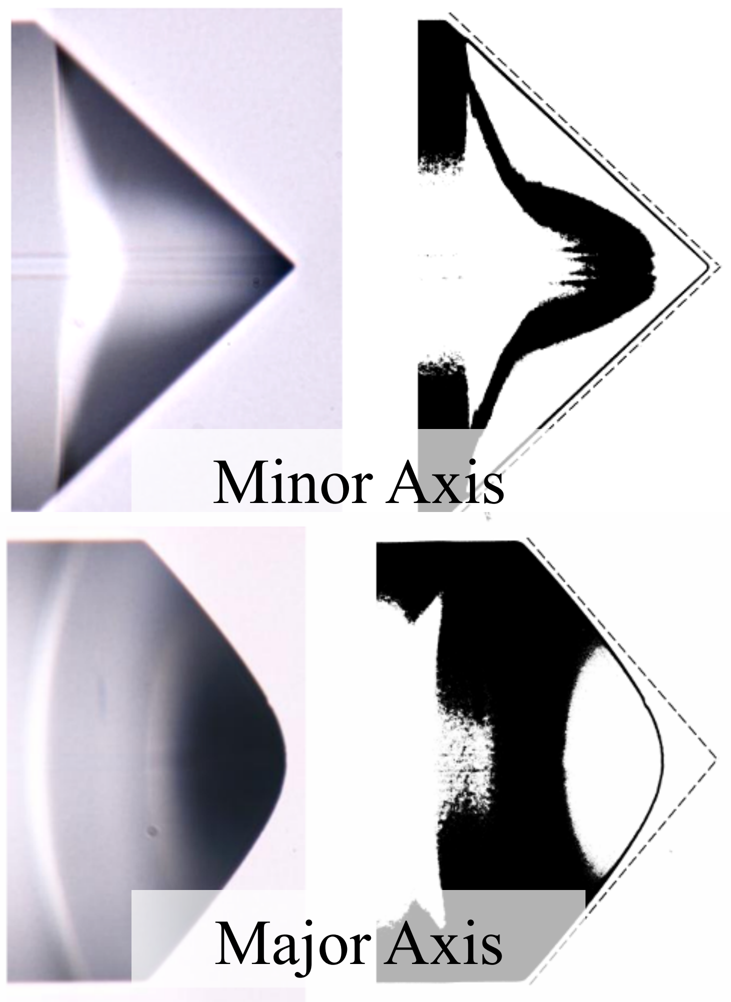


Feedings Hight (-H) v.s. Self-Rotation Angle (ϕ)

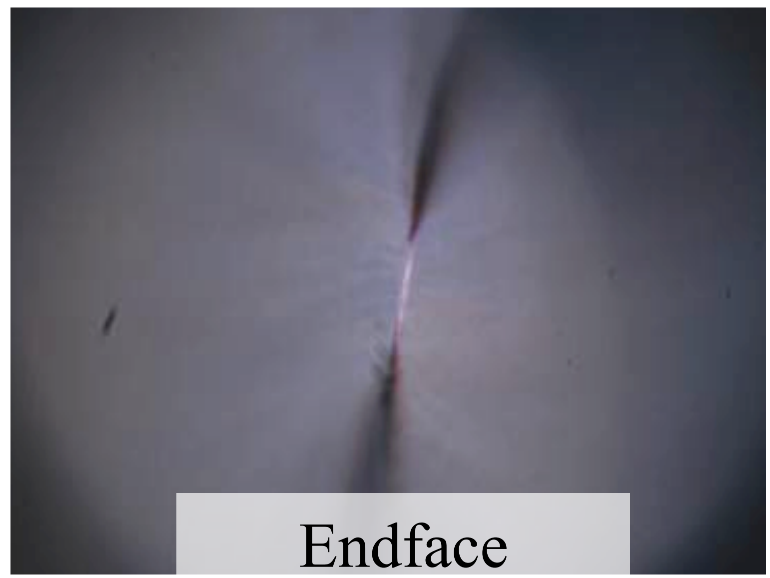


Y. D. Liu, Y. C. Tsai, L. J. Wang, Y. K. Lu, M. C. Hsieh, S. M. Yeh, and **W. H. Cheng**, "New scheme of double-variable-curvature microlens for efficient coupling high-power lasers to single-mode fibers," Journal of Lightwave Technology, 29, 898-904, (2011).

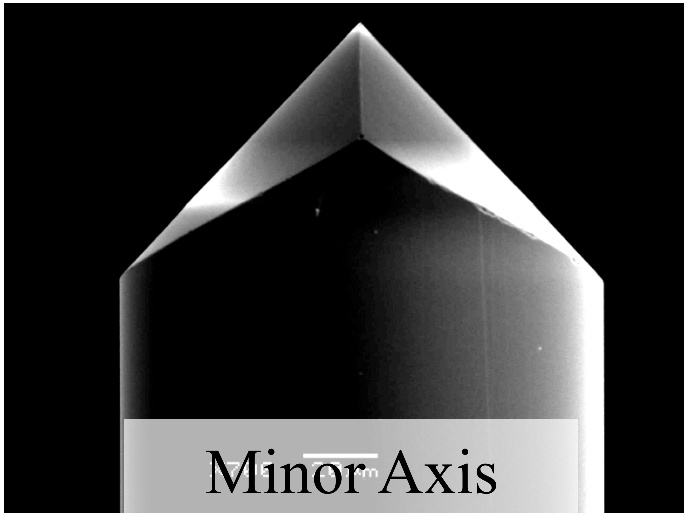
Optical Photos of Double-Variable -Curvature Fiber Endface (DVCFE)

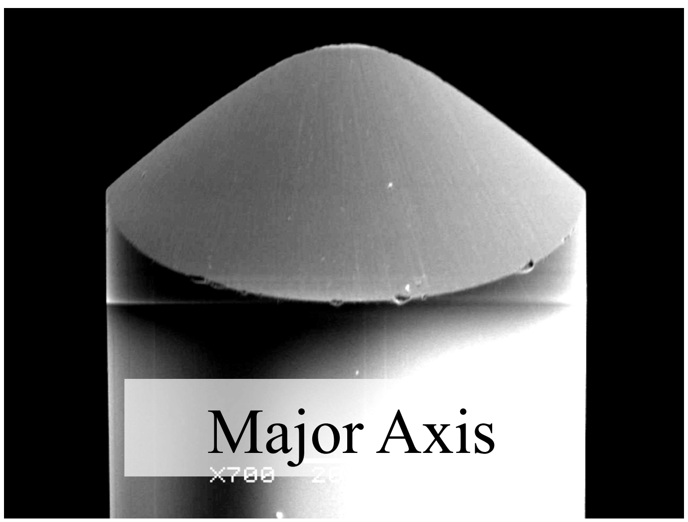


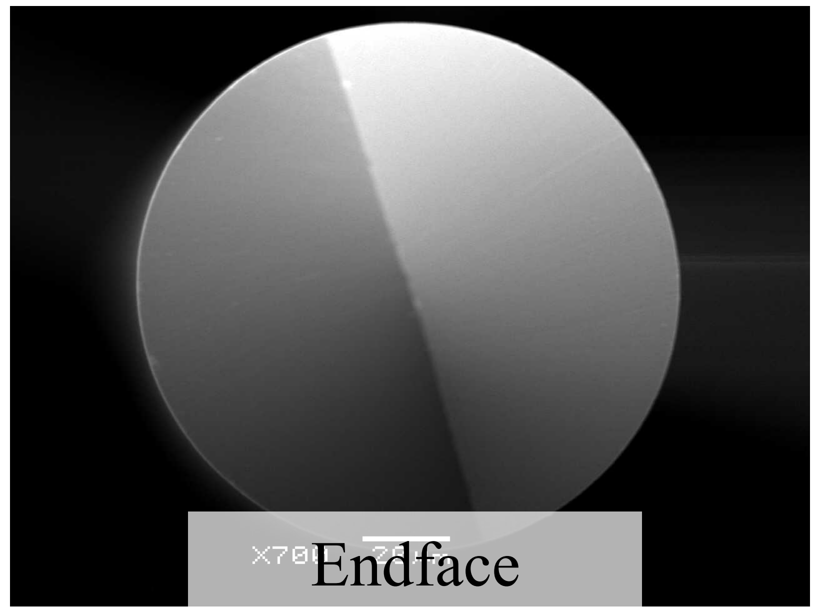
After grinding process



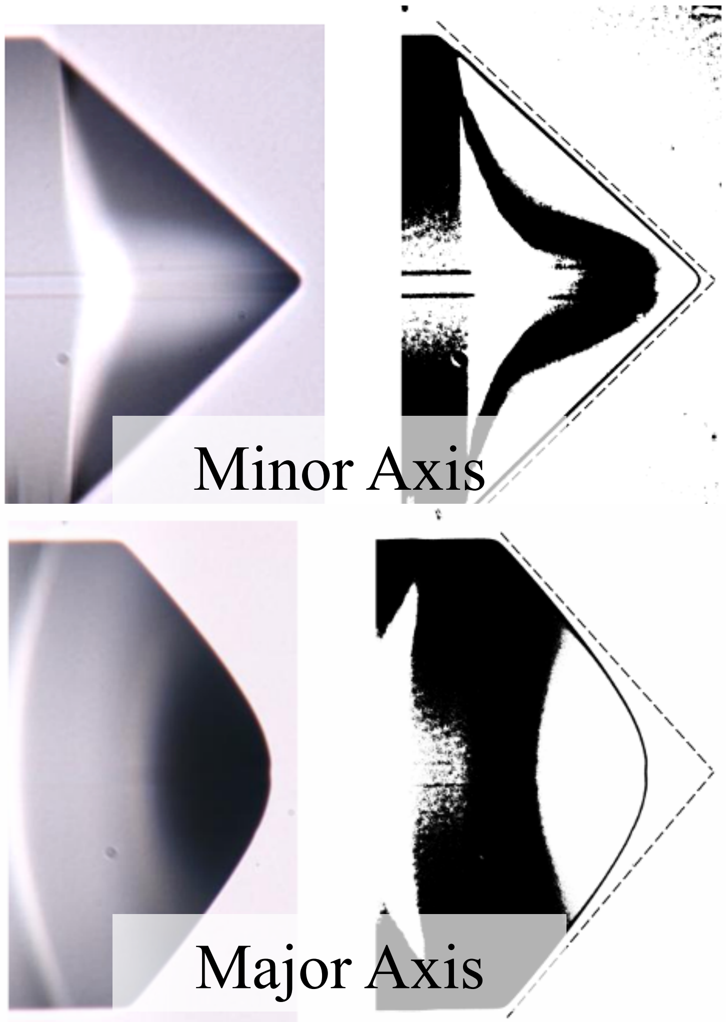
SEM of Endface (DVCFE)


Minor Axis

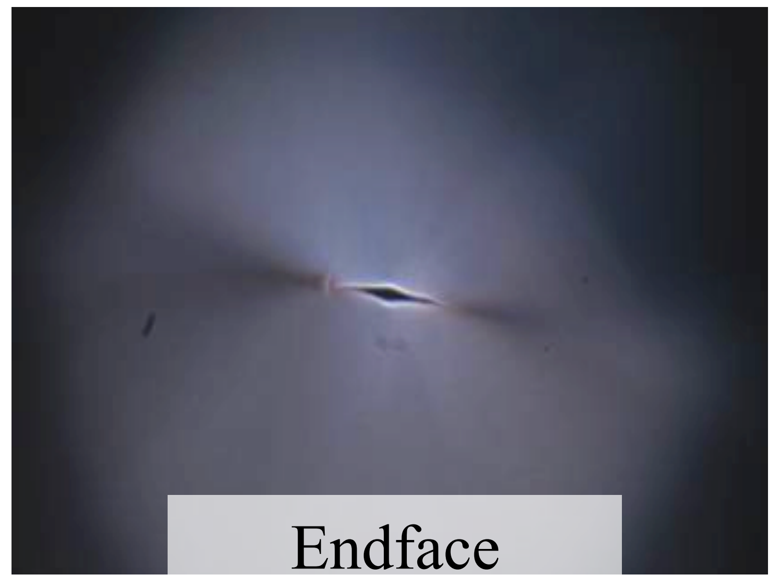

Major Axis


Endface

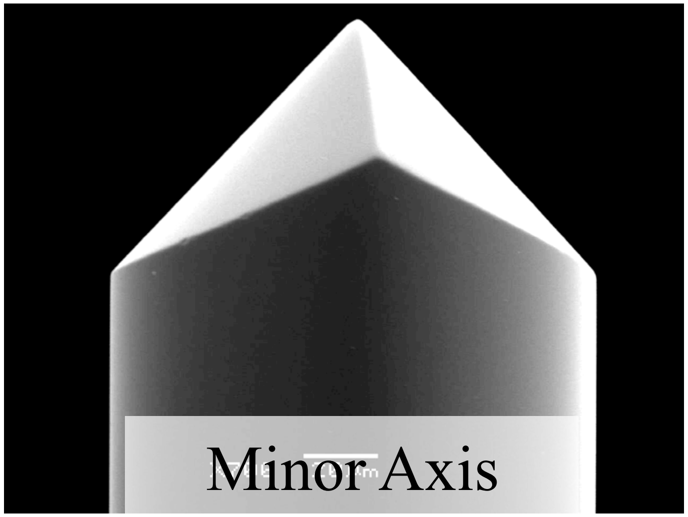
Optical Photos of Double-Variable -Curvature Microlens (DVCM)

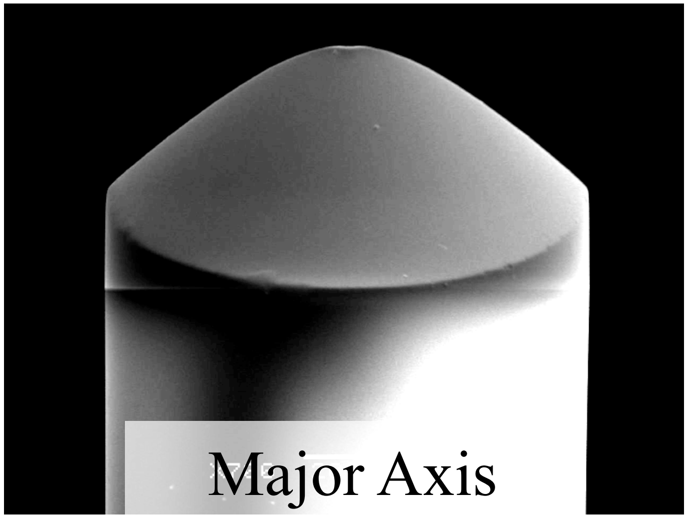


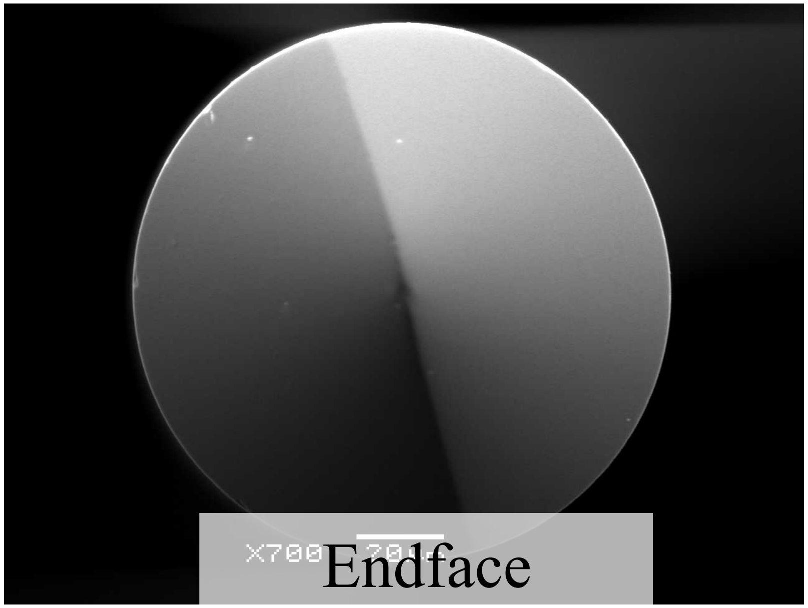
After slight fusion polish



SEM of Microlens (DVCM)

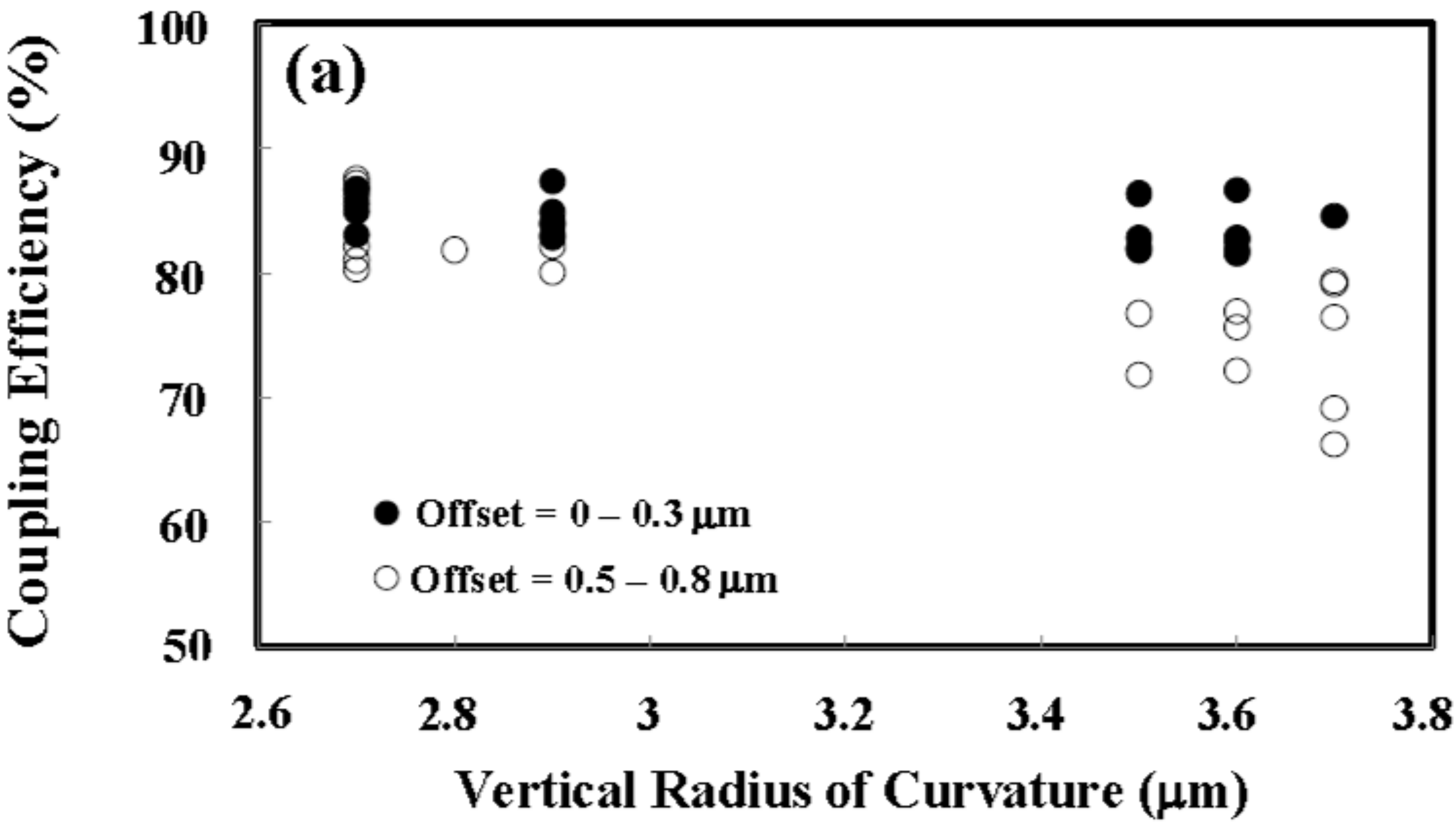




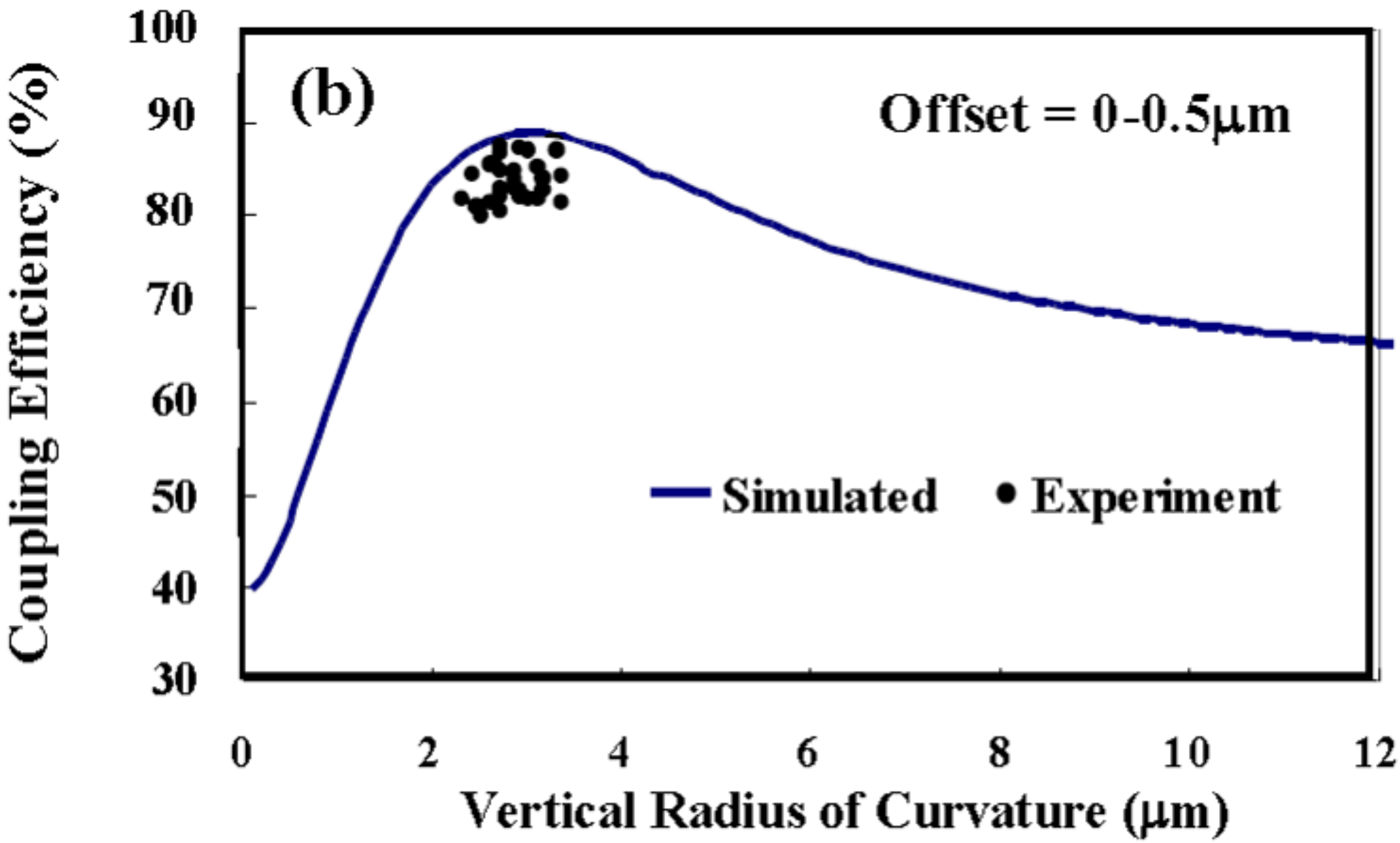


US patent : Double-Variable-Curvature Fiber Microlens
(Submitted, July 2011)

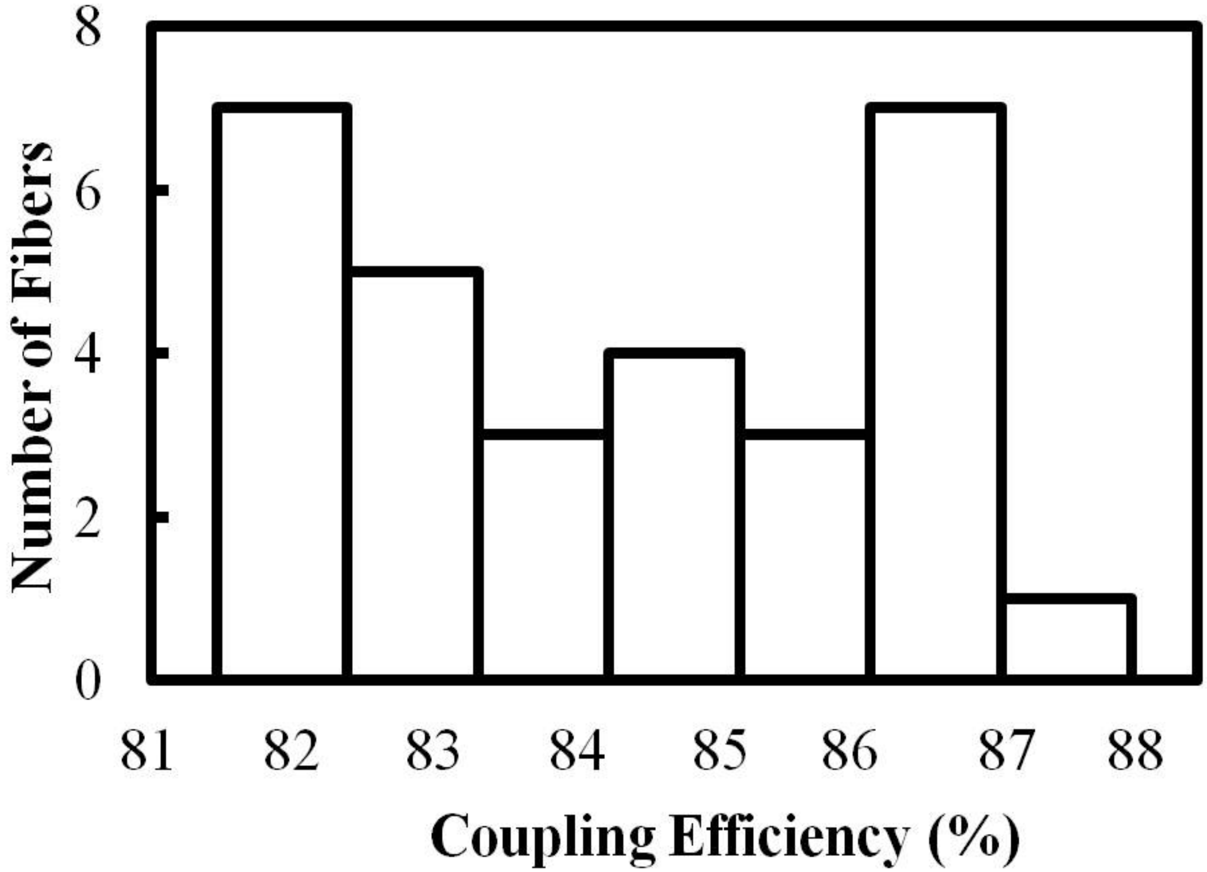
Coupling efficiency as a function of vertical radius of curvature for different offsets of DVCM



Coupling efficiency as a function of vertical radius of curvature for offset within 0.5 μm of DVCM

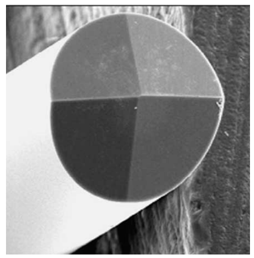
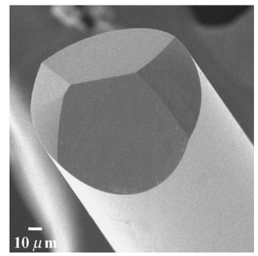
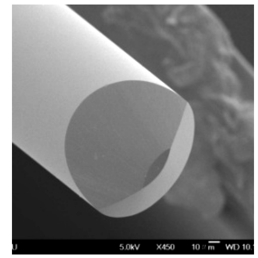
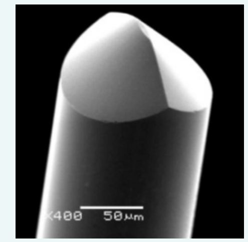


Histogram of measured coupling efficiencies between 980-nm laser diode and DVCM



Average coupling efficiency = 84.5%

Comparison Structures of Asymmetric Fiber Endface (QPSFE,CWSFE,AESFE,DVCFE)

	QPSFE	CWSFE	AECSFE	DVCFE
Shape				
Grinding step	4	3	1	1
Range/average offset (μm)	2.3/1.5	1.2/0.9	0.8/0.4	0.5/0.2
Max./Ave Coupling Efficiency	83%/	84%/	85%/71%	88%/84.5%
Advantage	High coupling efficiency.	High coupling efficiency.	High coupling efficiency, single-step grinding technique.	Higher yield and high coupling efficiency, single-step grinding technique.
Disadvantage	Low yield, multi-step grinding processes, fusing process.	Low yield, multi-step grinding processes, fusing process.	Low aspect ratio, requires fusing process.	

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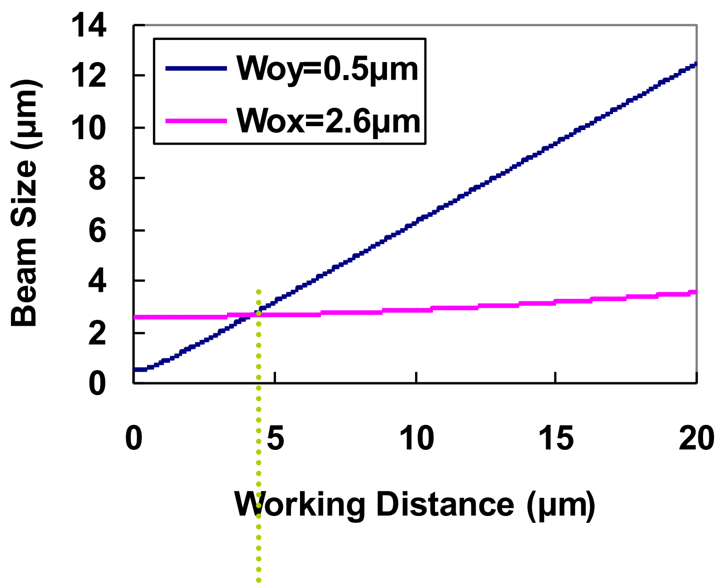
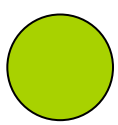
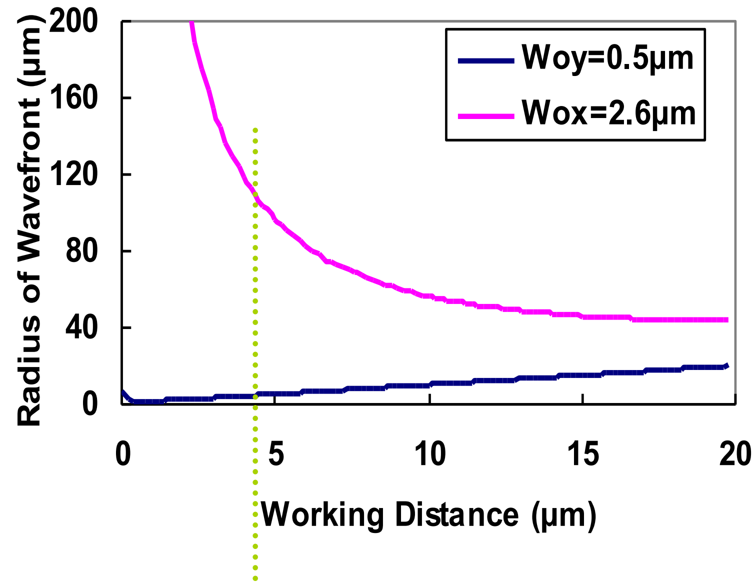
Mode Matching of Microlens Design

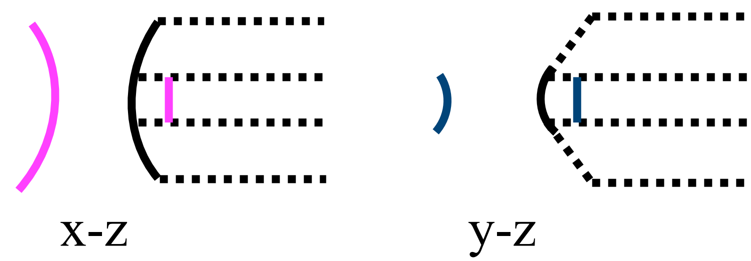




$$\omega_x(z) = \omega_y(z) \sim \omega_f$$

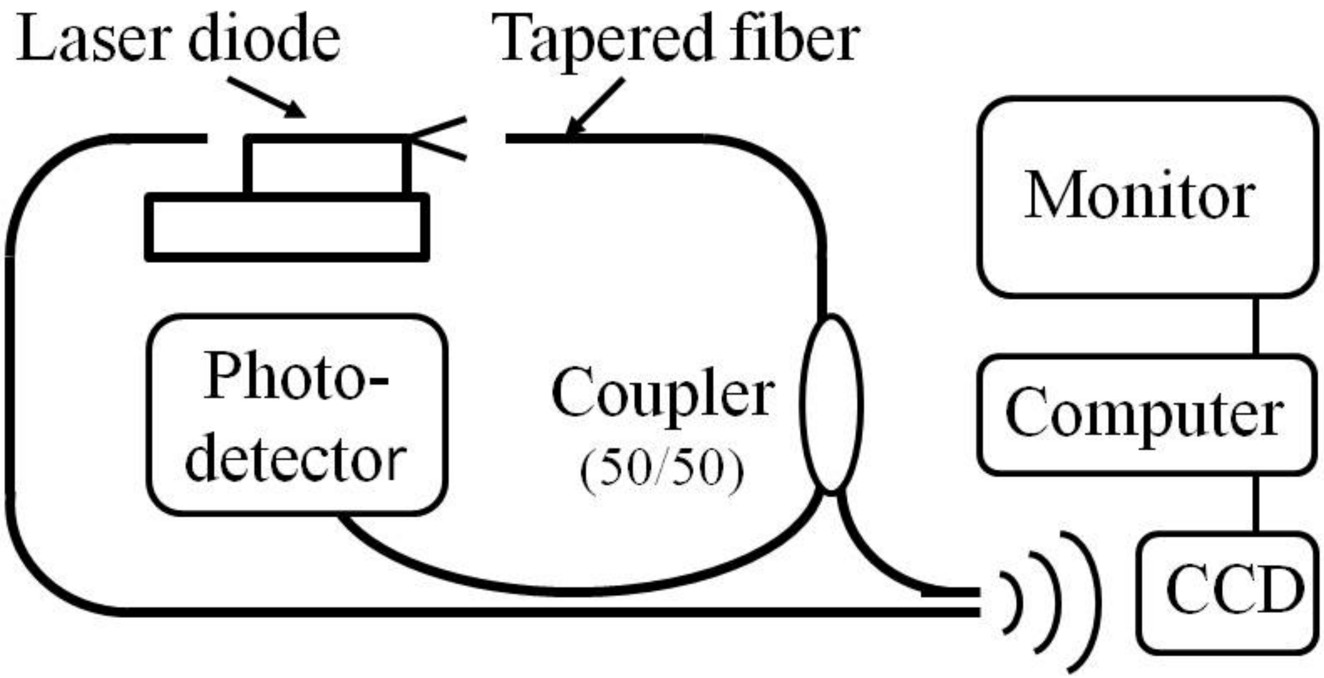
(a) Spot size matching





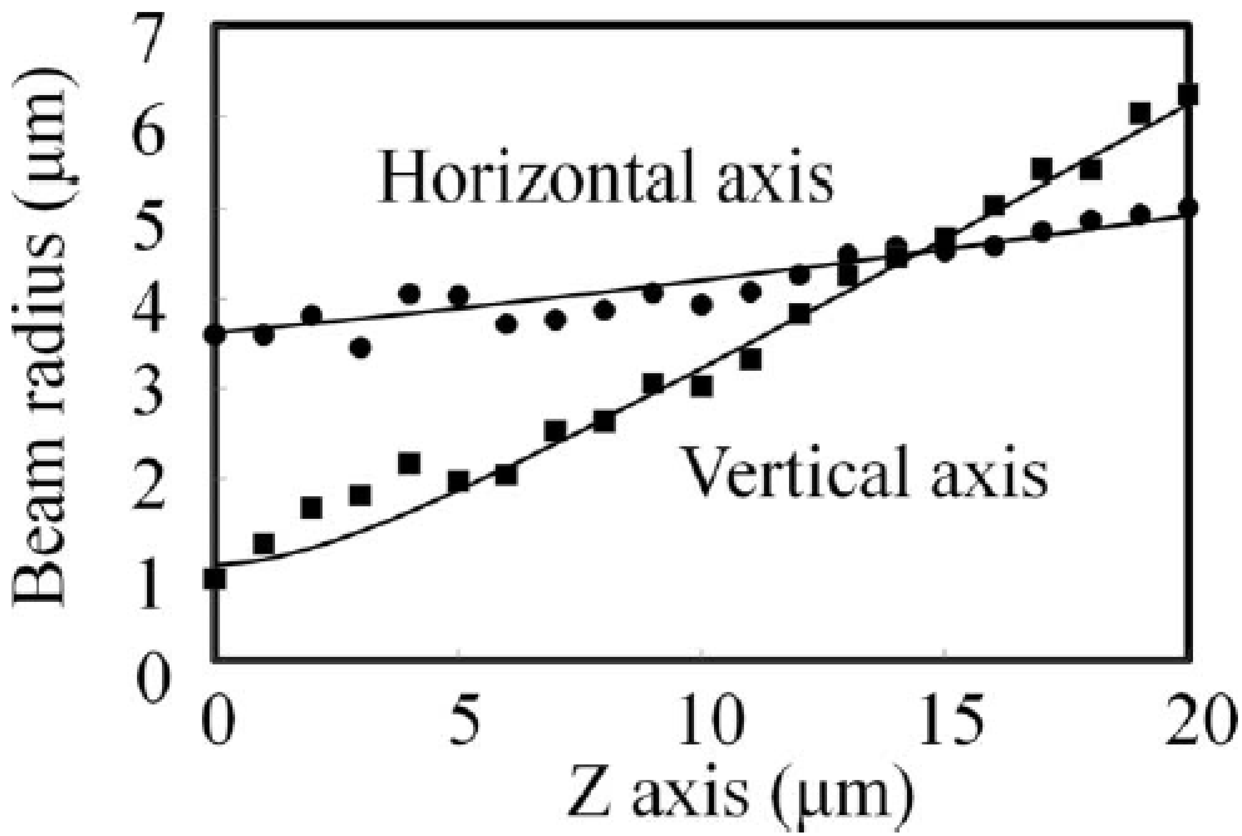
(b) Wavefront matching

Near-Field Measurement of Laser Diode



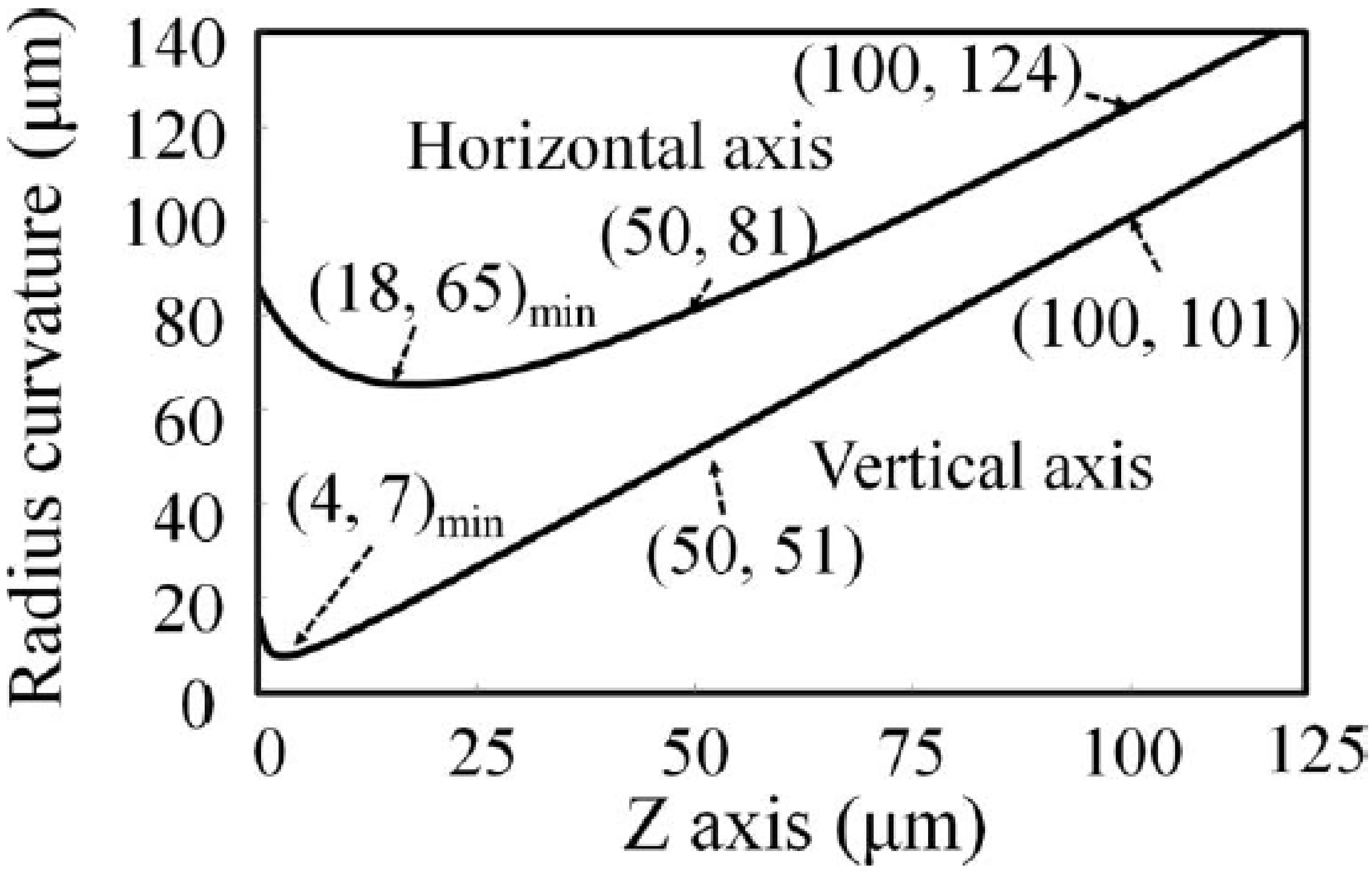
Y.K. Lu, P. Yeh, and **W.H. Cheng**, "Direct Near-Field Phase Measurement of Laser Diodes Employing Single-Mode Fiber Interferometer," Opt. Letts. 35, 3643 (2010).

Beam Widths Obtained by Intensity Distribution and Gaussian Beam Fittings



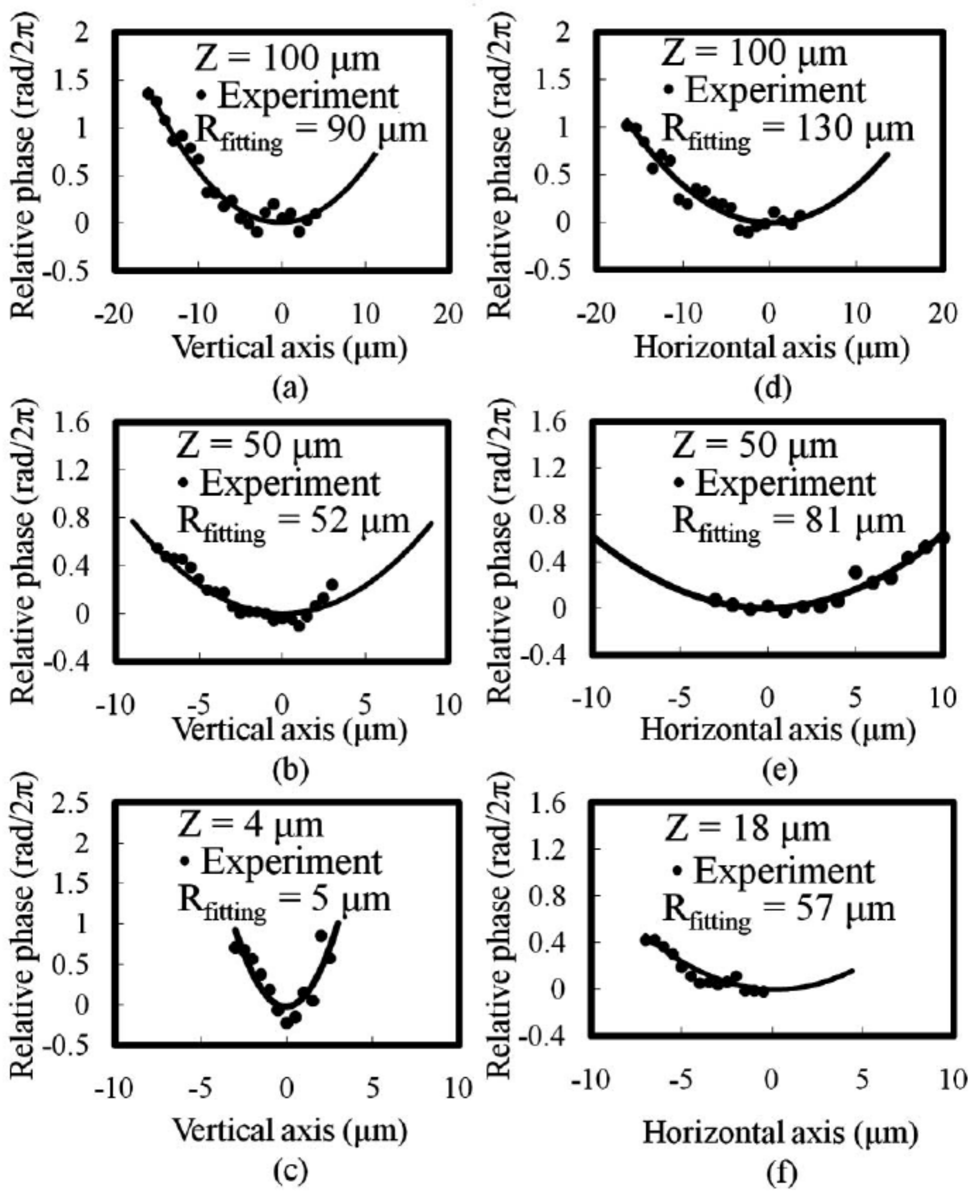
$z = 0 : R_x = 3.6\ \mu m$ and $R_y = 0.9\ \mu m$

Radius Curvature of Wavefront



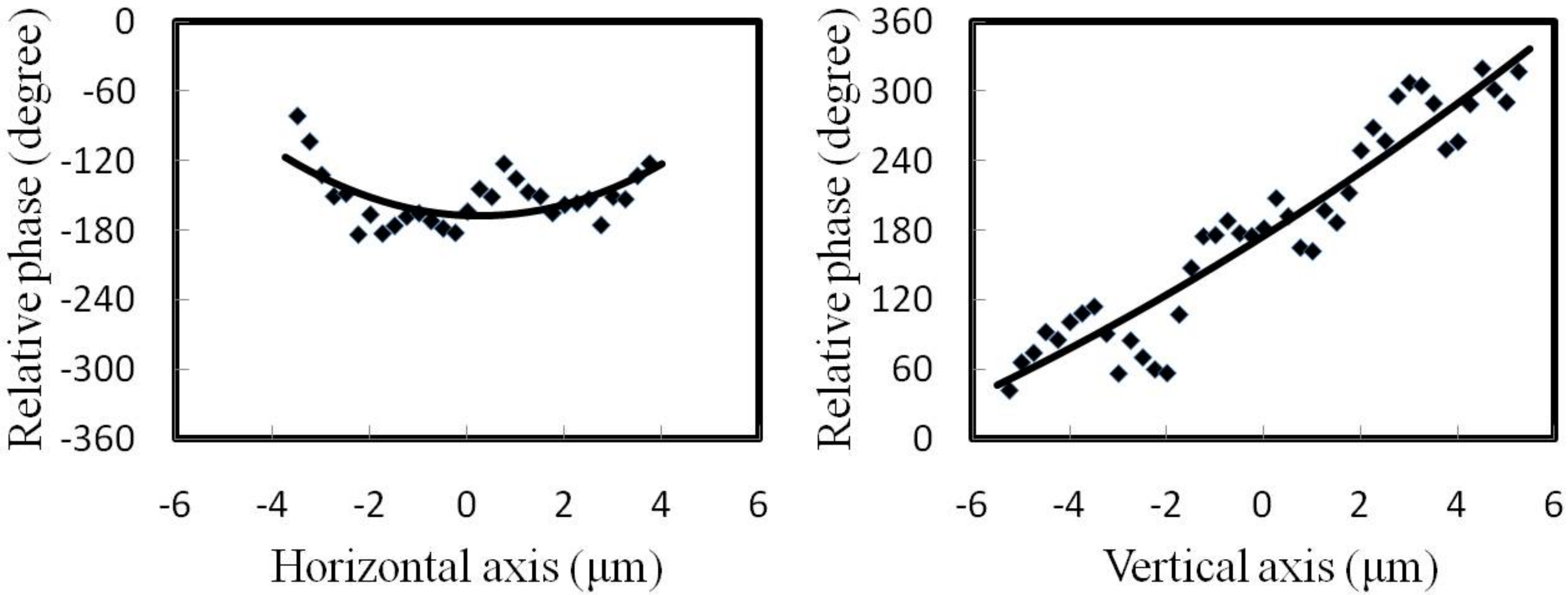
z = 0: R_x = 85.9 μm and R_y = 15.7 μm

Relative phase distributions of laser along the vertical and horizontal axes



Curved Wavefront

Phase distributions of fiber along the vertical and horizontal axes



z = 0: R_x = 58 μm and R_y = 338 μm

Planar Wavefront

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Conclusion

- We are able to fabricate any kinds of perfect microlenses employing a single-step grinding technique with fully automatic process, look like fabricate an **artwork**.
- The double-variable-curvature microlens (DVCM) was fabricated by precisely controlled both grinding offset and radius curvature leading to high-average and maximum coupling efficiency of 84.5% and 88%, respectively.
- High coupling photonics devices and modules require mode match (spot size and wavefront) between active and passive components. The measured radius curvature of wavefronts of laser diode and fiber employing near-field technique were in good agreement each other, the **science approach**.

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1. S.M. Yeh, S.Y. Huang, Y.K. Lu, H.H. Lin, and **W.H. Cheng**, "A Novel Scheme of Lensed Fiber Employing a Quadrangular-Pyramid-Shaped Fiber Endface for Coupling between High-Power Laser Diodes and Single-Mode Fibers, "J. Lightwave Technol., 22, 1374 (2004).
2. S.M. Yeh, S.Y. Huang, and **W.H. Cheng**, "A New Scheme of Conical-Wedge-Shaped Fiber Endface for Coupling between High-Power Laser Diodes and Single Mode Fibers," J. Lightwave Technol. 23, 1781 (2005).
3. Y.K. Lu, Y.C. Tsai, Y.D. Liu, S.M. Yeh, C.C. Lin, and **W.H. Cheng**, "Asymmetric Elliptic-Cone-Shaped Microlens for Efficient Coupling to High-Power Laser Diodes," Opt. Express. Feb. 15, 1434 (2007).
4. Y.C. Tsai, Y.D. Liu, C.L. Cao, Y.K. Lu, and **W.H. Cheng**, "A New Scheme of Fiber End-Face Fabrication Employing Variable Torque Technique," J. Micromech. Microeng. 18, 055003-9 March (2008).
5. Y.D. Liu, Y.K. Lu, Y.C. Tsai, S.M. Yeh, C.C. Lin, and **W.H. Cheng**, "New Scheme of Double-Variable-Curvature Microlens for Efficient Coupling High-Power Lasers to Single-Mode Fibers," J Lightwave Technol. 29, 898 (2011).
6. Y.K. Lu, P. Yeh, and **W.H. Cheng**, "Direct Near-Field Phase Measurement of Laser Diodes Employing Single-Mode Fiber Interferometer," Opt. Letts. 35, 3643 (2010).

專　利

1. **鄭木海**,蔡穎堅, 劉育達, 謝銘駿**,**呂昱寬, "雙變曲率光纖透鏡"(美國專利及中華民國專利審查中)
2. **鄭木海**,葉斯銘"錐形楔形光纖透鏡及製造方法"(美國專利US7515789 B2 (2009))。
3. 蔡穎堅,呂昱寬, 劉育達, **鄭木海** "光纖端面之非軸對稱研磨方法及其裝置"(美國專利US7494399 B2 (2009) 及中華民國專利(299688)(2008))。
4. **鄭木海**,葉斯銘"錐形楔形光纖透鏡及製造方法"(美國專利US7295729 B2 (2007) 及(中華民國專利255358(2006))。
5. 呂昱寬, 葉斯銘,**鄭木海**,"四角錐形光纖透鏡及其製法"(中華民國專利092118496 (2006)。
6. **鄭木海**,楊惠民,李兆偉,王世宏, "製造雙曲線形式光纖透鏡之方法"(中華民國專利093119650(2005))。
7. **鄭木海**,楊惠民,張世恩,李兆偉,"製造軸對稱光纖透鏡之方法"(中華民國專利206243)(2004))。

Thanks for your attention