



Research Progress of High Resolution Astrophotonical Chip Spectroscopy

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Astrophotonics Research Team, NIAOT



- **PI**
Prof. Jinping He / 何晋平
- **Research topics**
 - **VIPA hi-res spectrometer**
 - **Chip spectrometer**

Outline



- 1. Background**
- 2. High resolution waveguide array spectroscopic chip**
- 3. Flat type beam splitter chip**
- 4. Conclusion and prospective**

Outline



1. Background

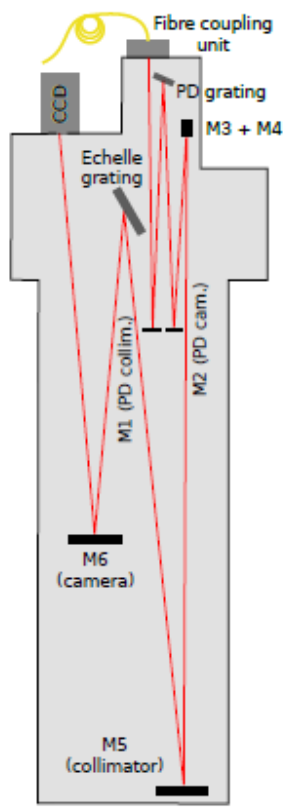
2. High resolution waveguide array
spectroscopic chip

3. Flat type beam splitter chip

4. Conclusion and prospective

Astronomical spectrograph faces challenges

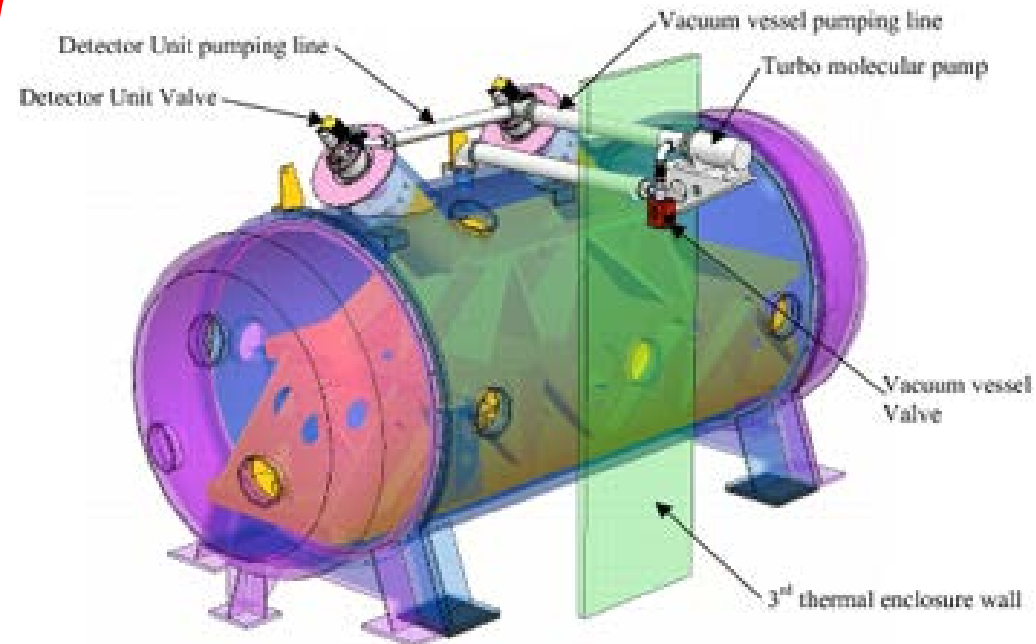
> 10 m



VTT spectrograph
Resolution : 0.5~1 million

1. Huge & Expensive

2. Extremely high accuracy & Difficulty



ESO-VLT ESPRESSO
Resolution : 70~190 k
Accuracy : ~30 cm/s

How to obtain a

- **compact**
- **low-cost**
- **high resolution**
- **broadband**

astronomical spectrograph?

Solutions?



Grating in ESPRESSO

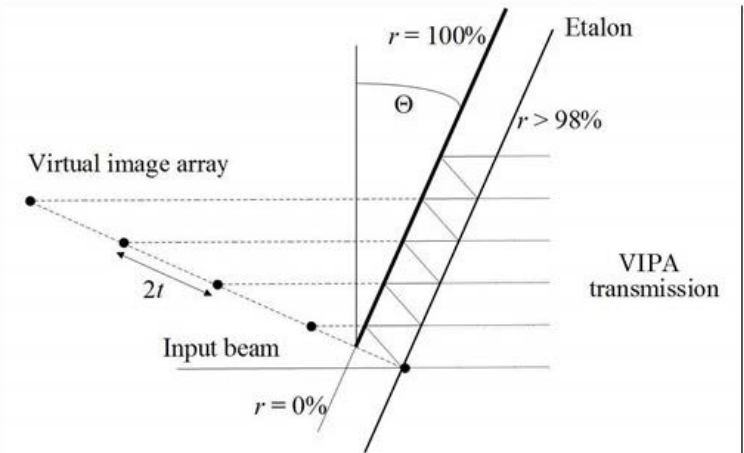
Size: 1.2 m

Limited dispersion !

Replace grating?

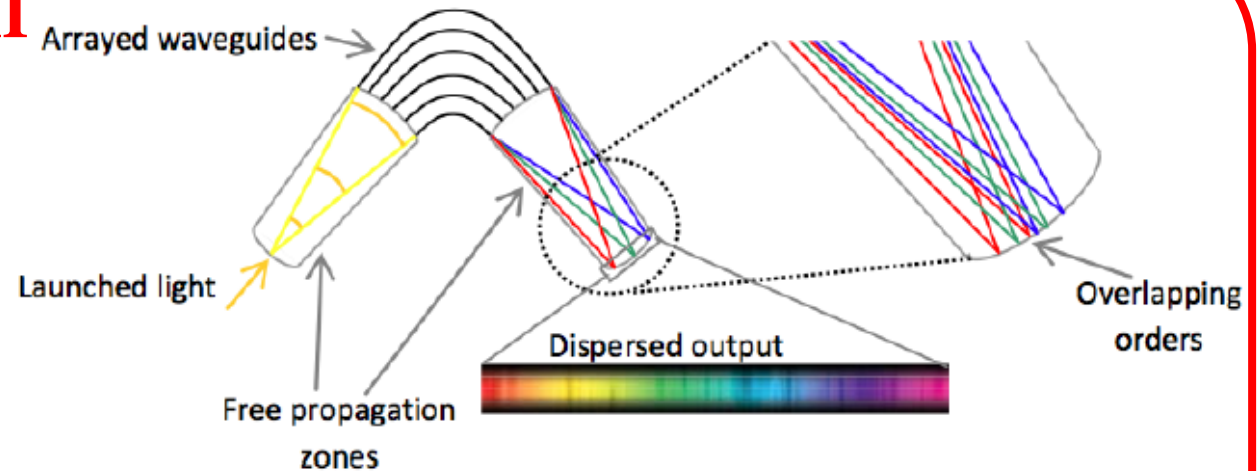


I



VIPA -- Extremely high dispersion

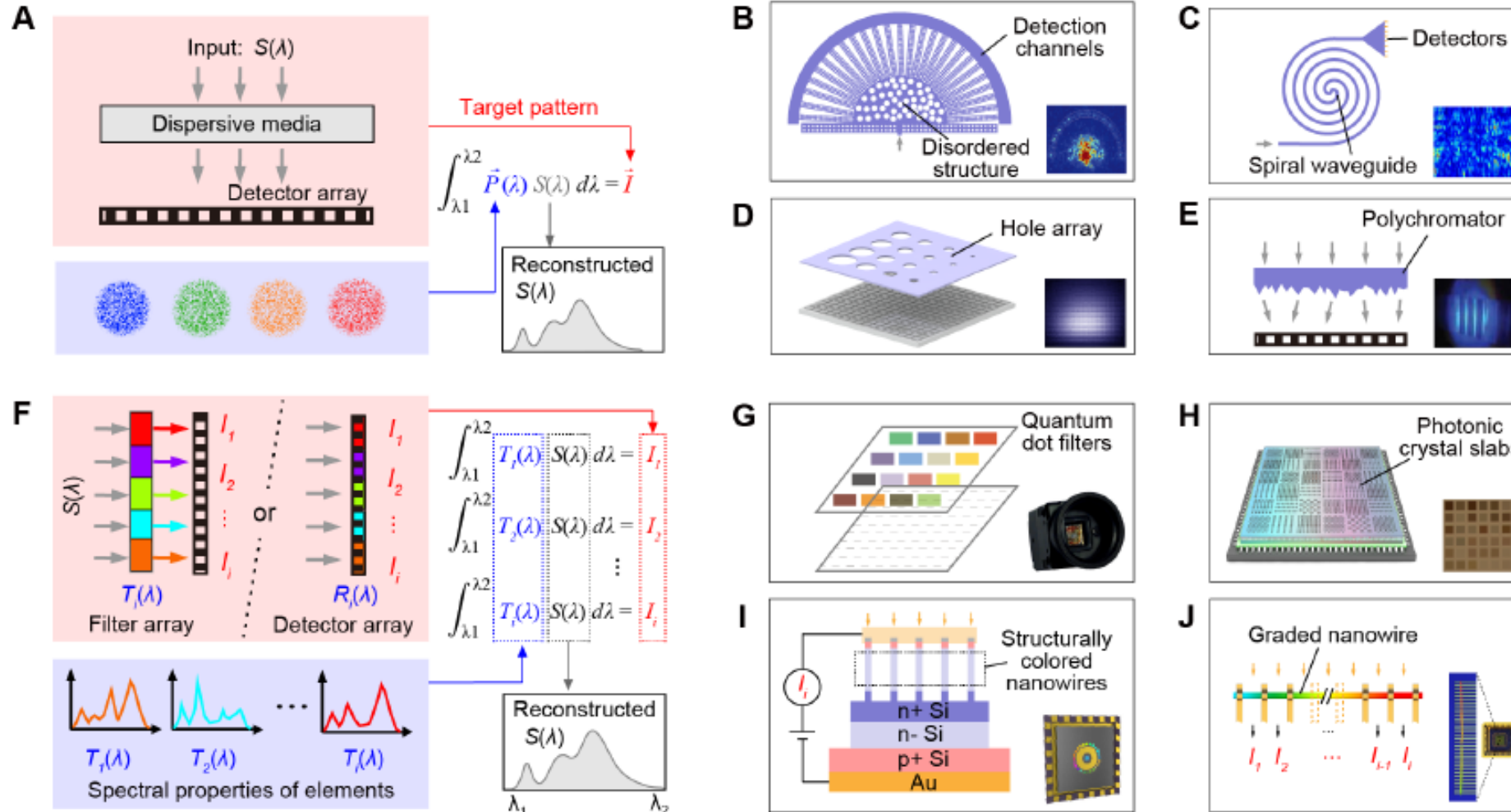
II



Chip spectrometer -- Integrated Optics

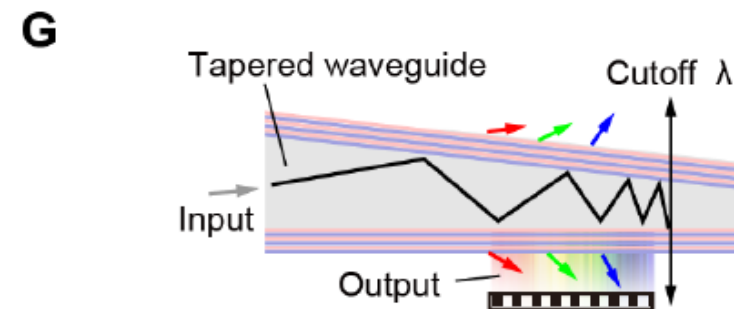
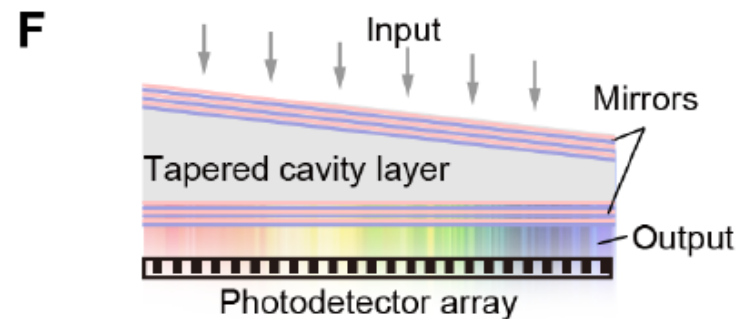
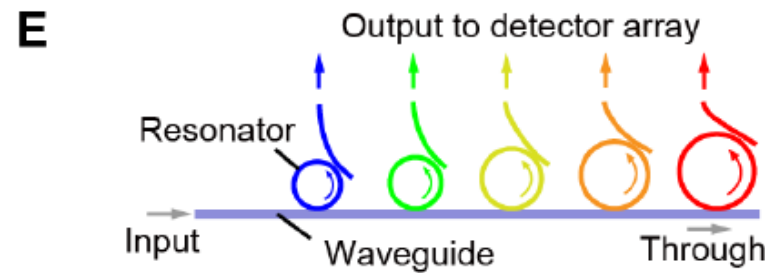
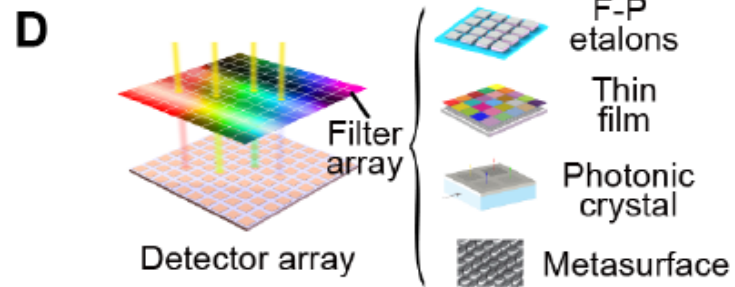
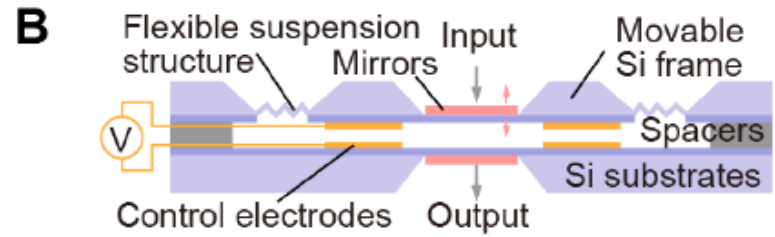
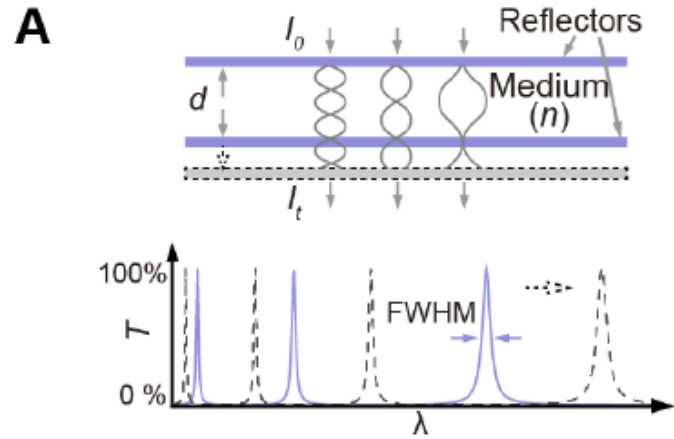
Chip spectrometer: Status

Type I Computational spectrograph



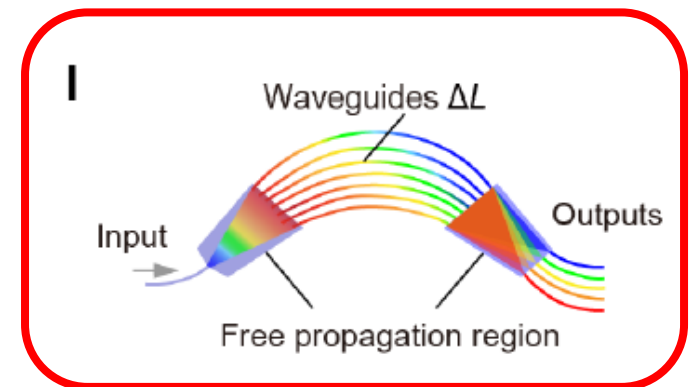
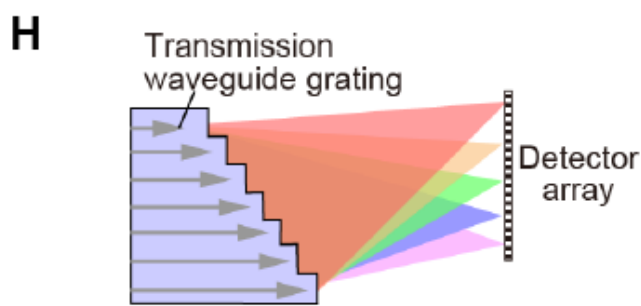
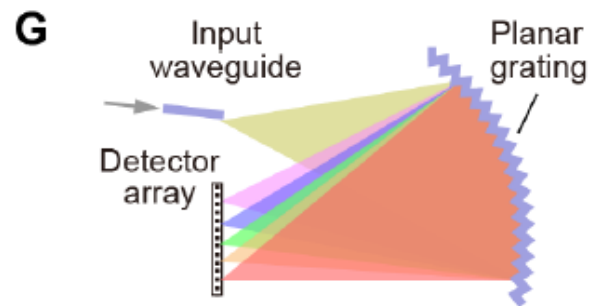
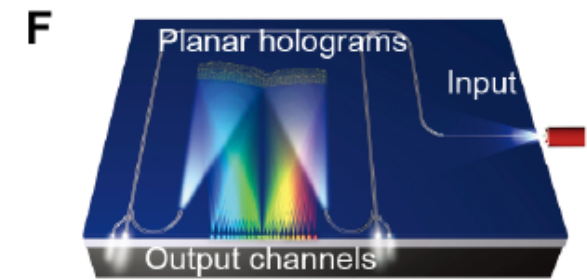
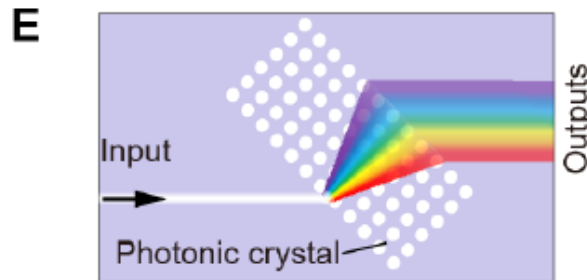
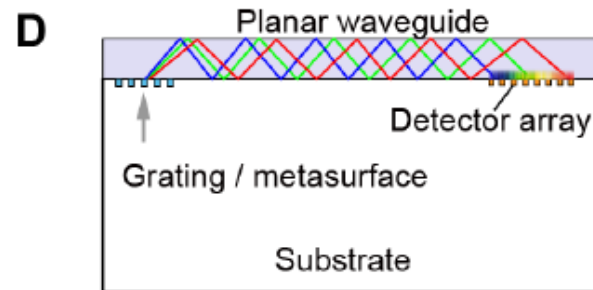
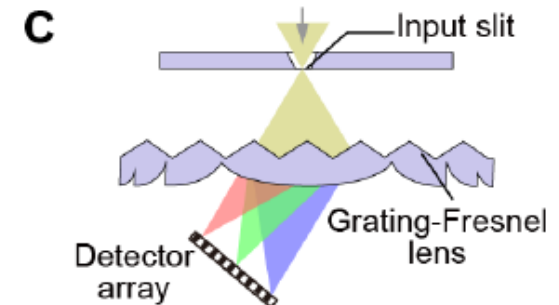
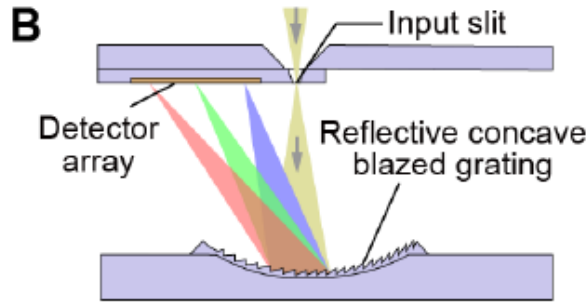
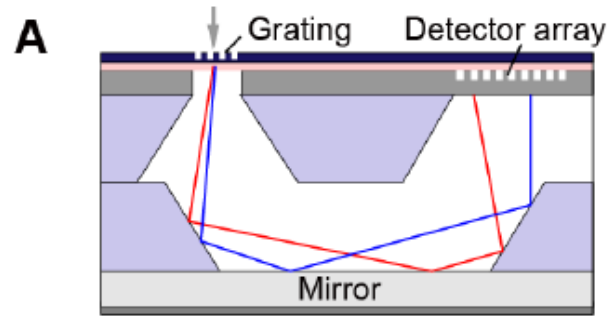
Limited performance, esp. low SNR case

Type II Cascaded filters

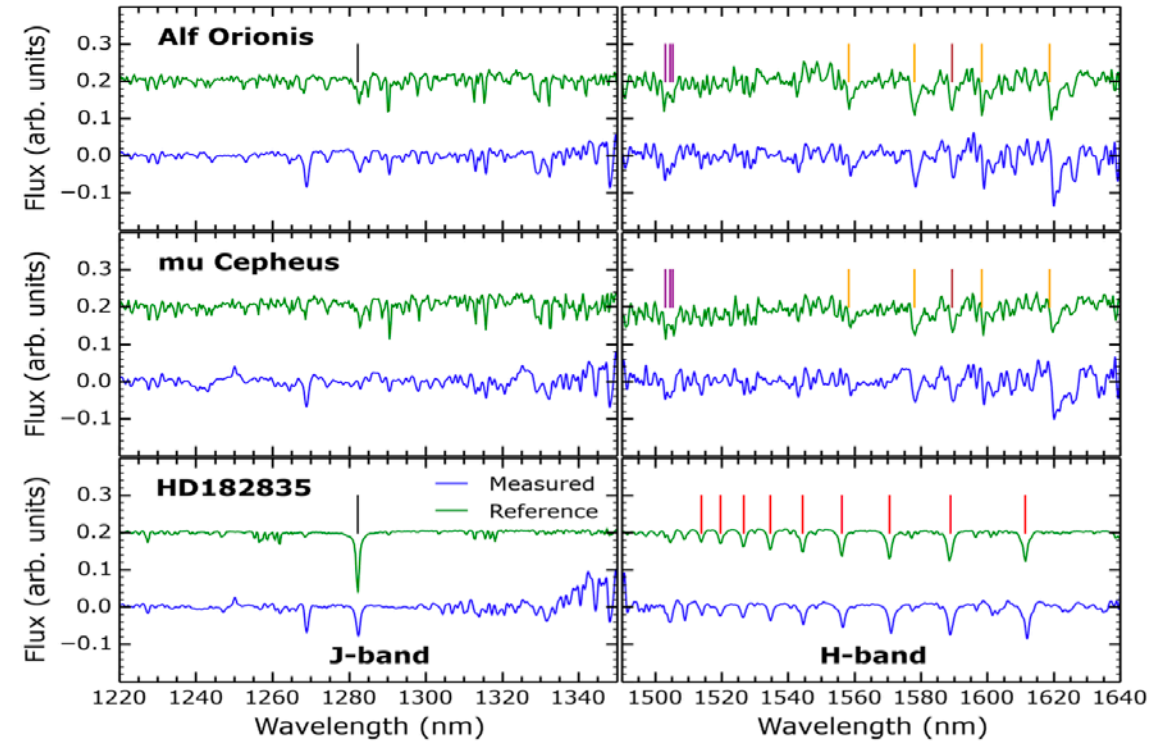
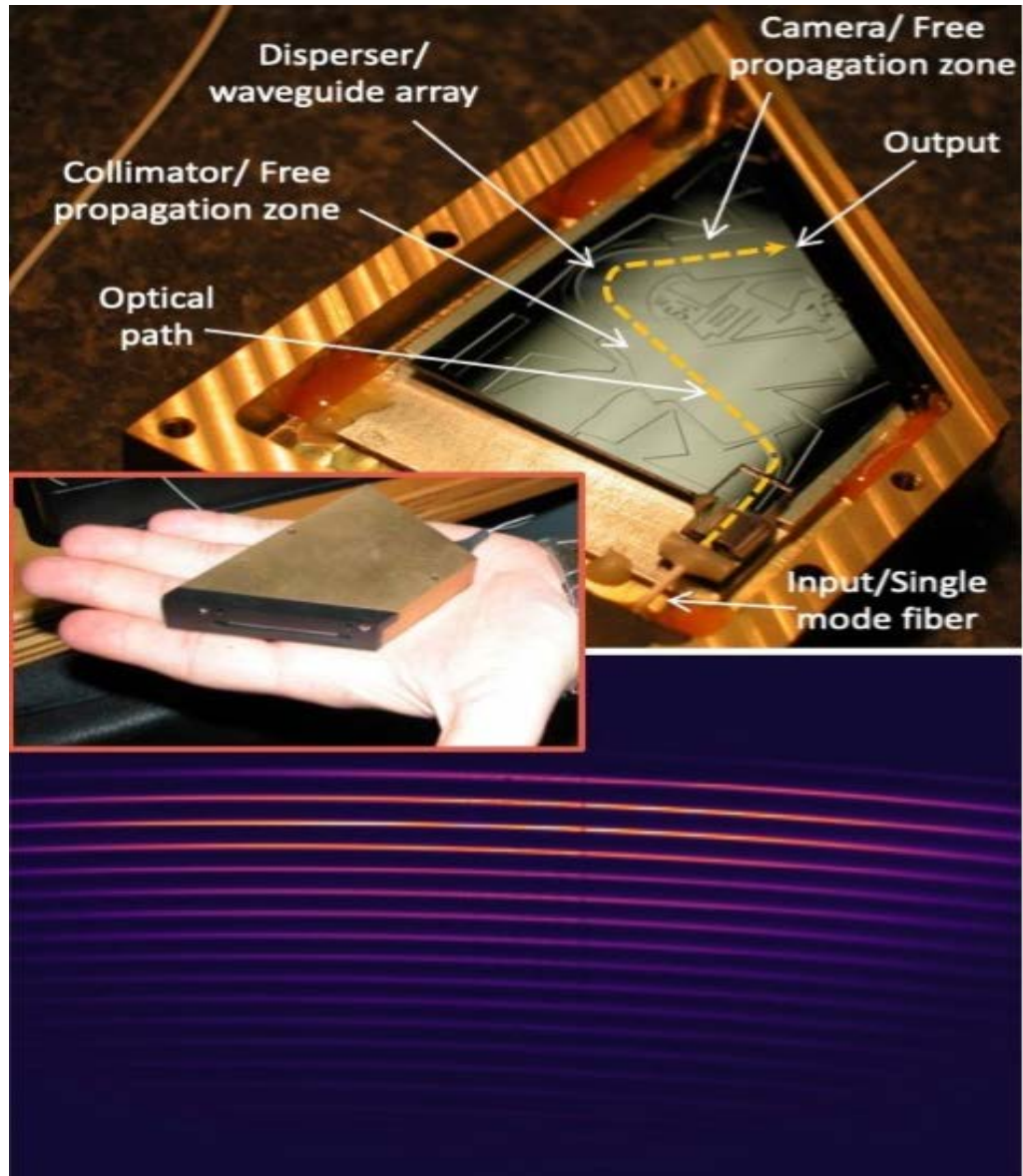


**Limited channels:
bandwidth vs.
resolution**

Type III Directly dispersion



On-sky demonstration on Subaru



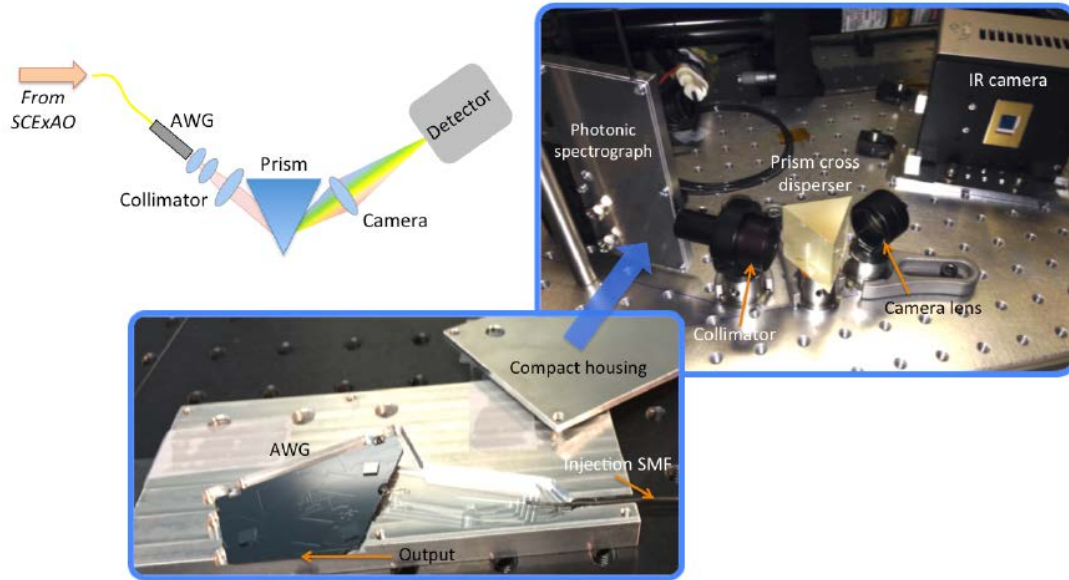
Typical results

Throughput: ~5%

Resolution: 2,000~5,000

Spectral range: 1.2~1.65 μm

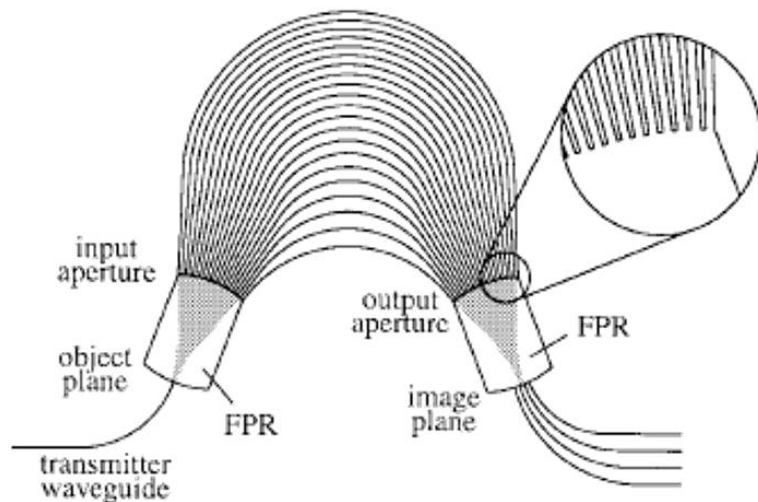
Problems for waveguide array spectrometer



(1) Limited resolution

(2) Half-integration

(3) Single-mode fiber input



Outline



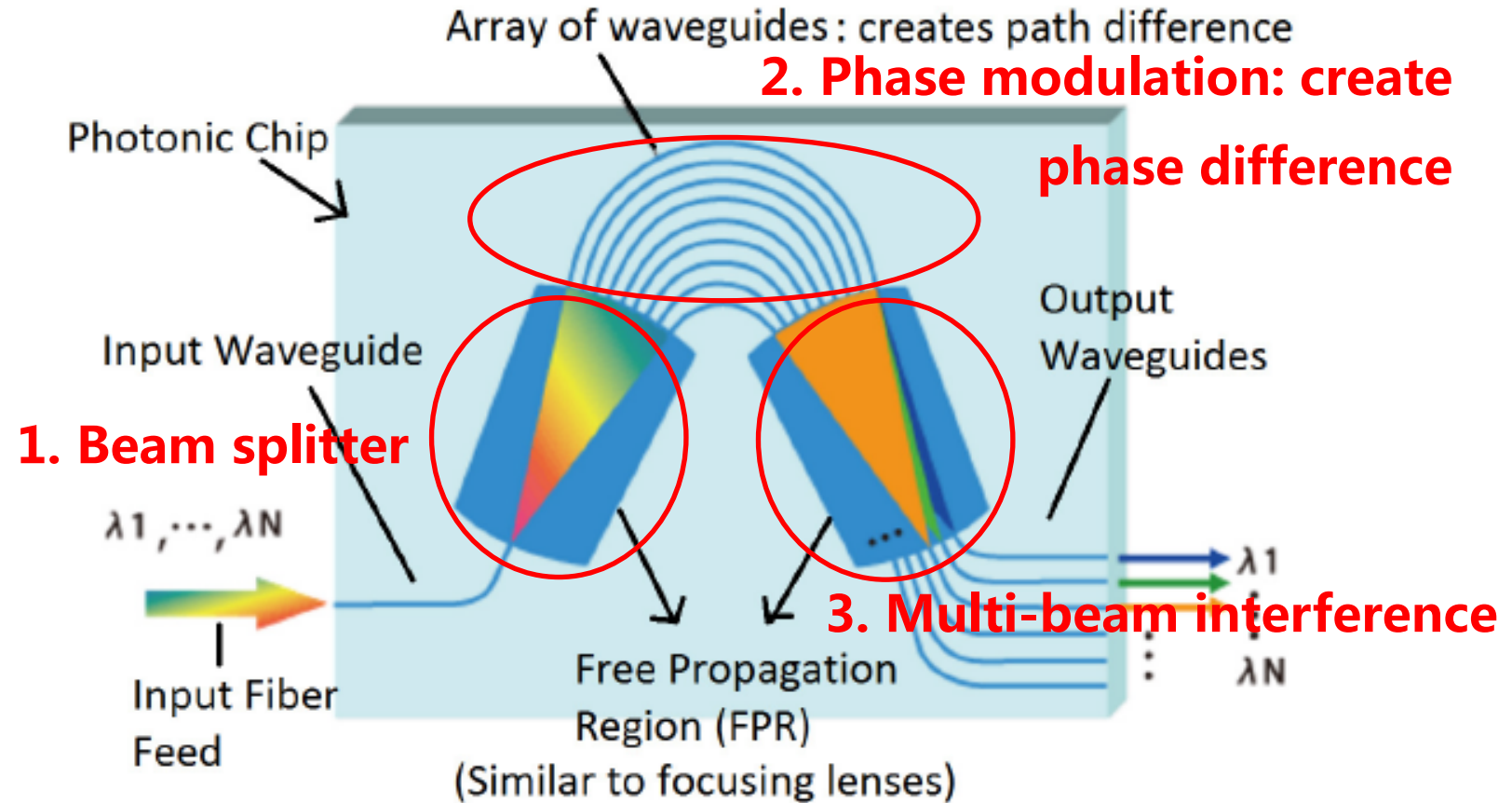
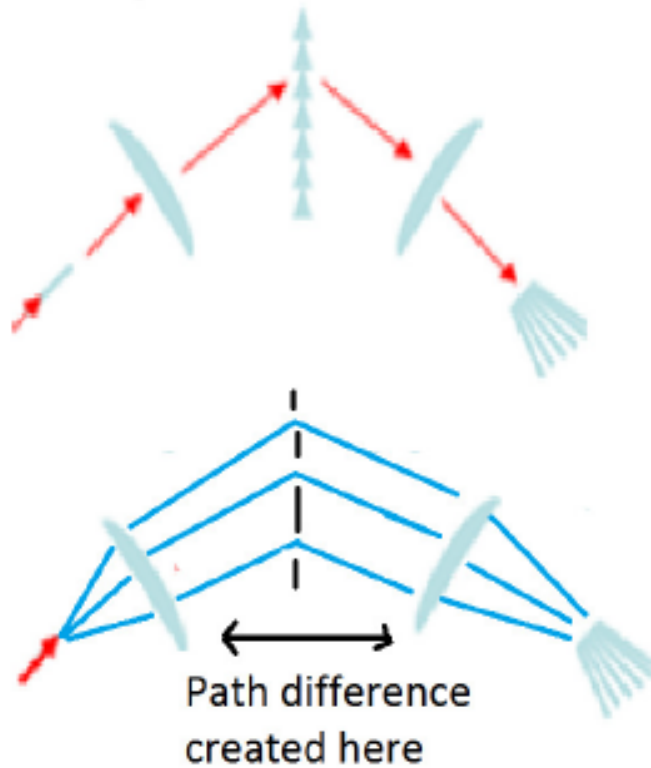
1. Background

**2. High resolution waveguide array
spectroscopic chip**

3. Flat type beam splitter chip

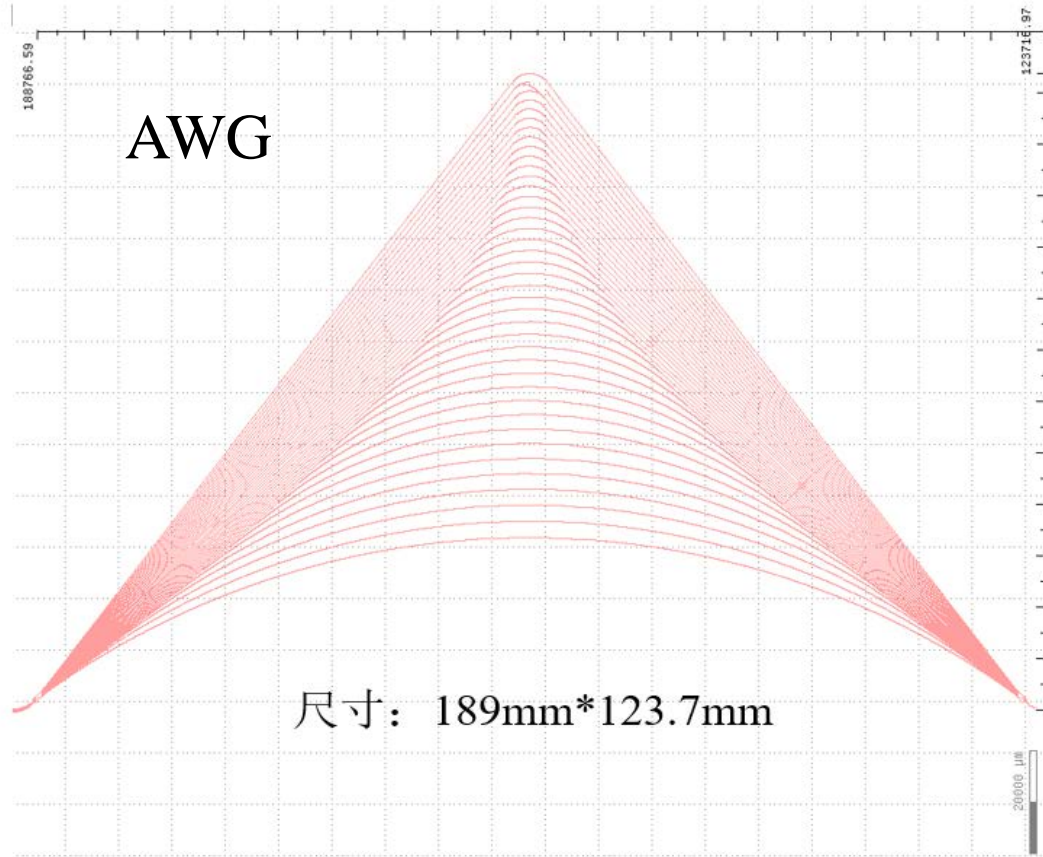
4. Conclusion and prospective

Dispersion mechanism of waveguide array

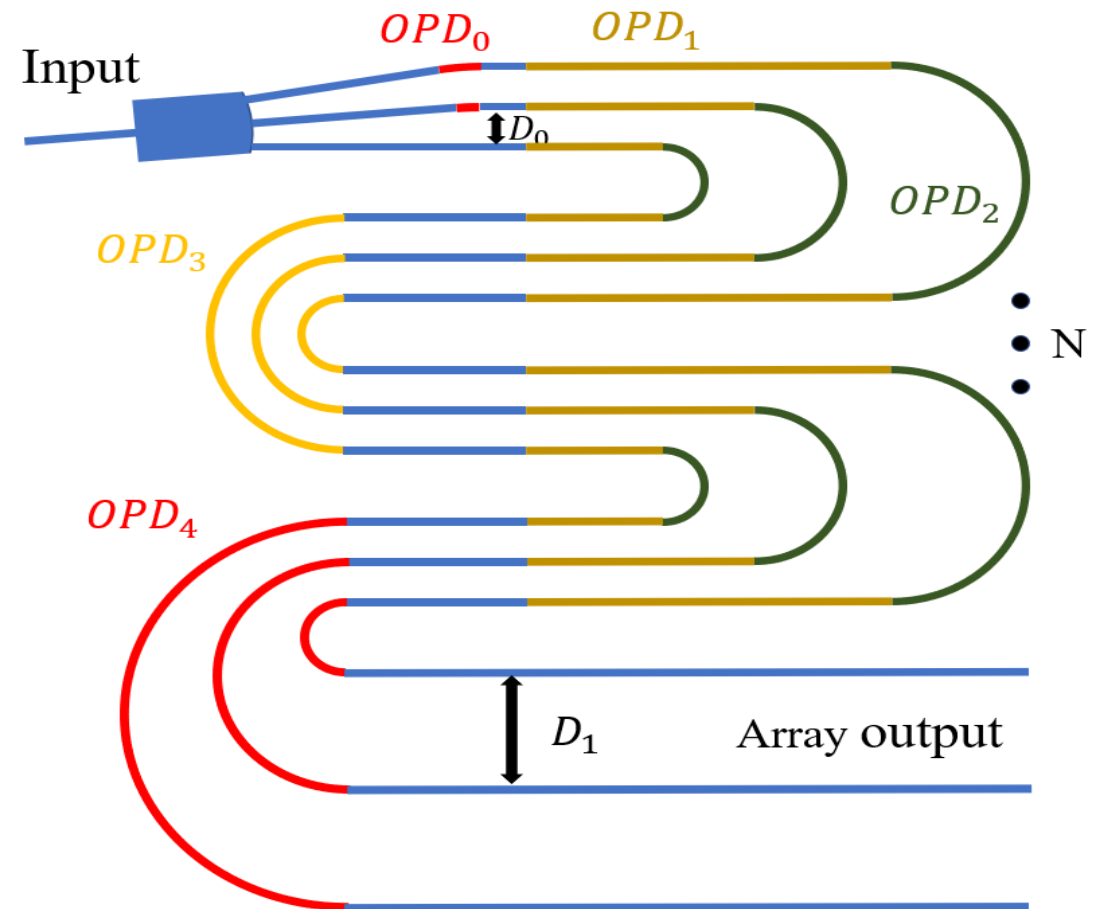


Phase array, multi-beam interference

Our solution: Cascaded phase modulation



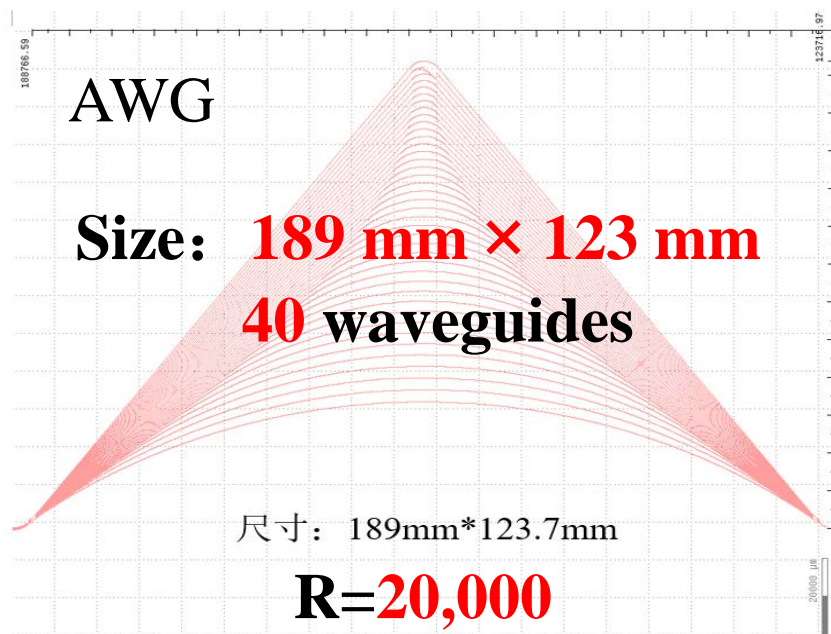
Common AWG structure



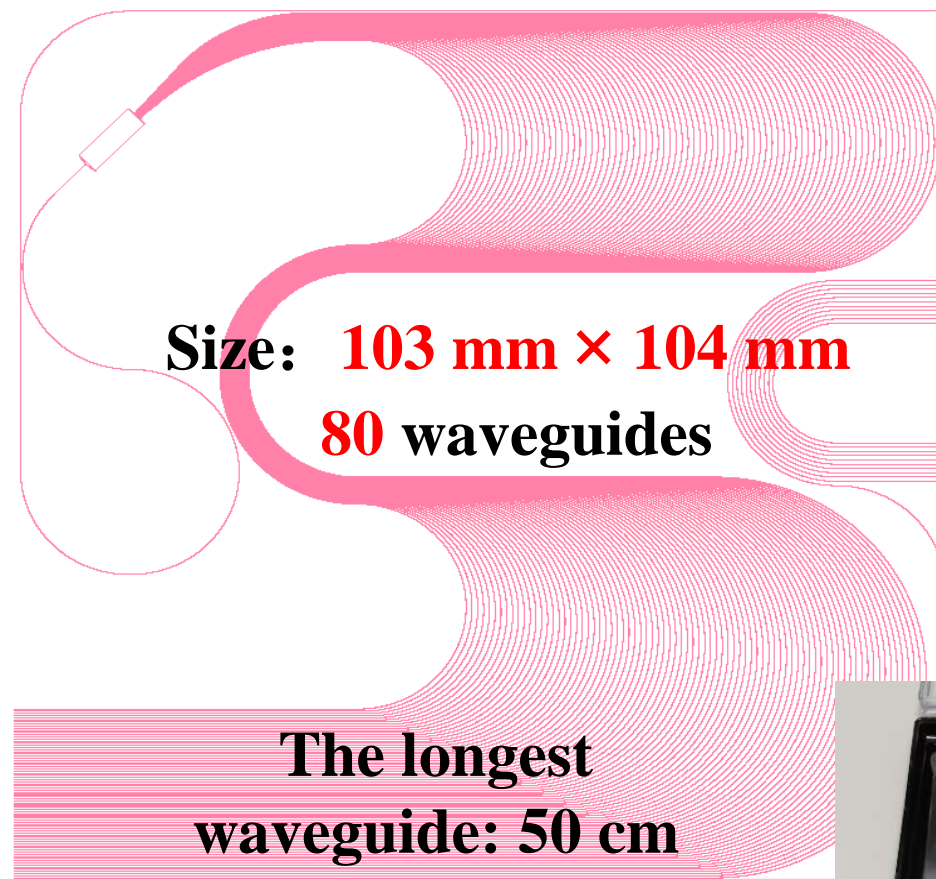
Cascaded phase modulation

Chip design: AWG Vs. Cascaded phase modulation structure

Waveguide:
SiO₂/Ge-doped SiO₂
6.5 μm × 6.5 μm



Common AWG structure

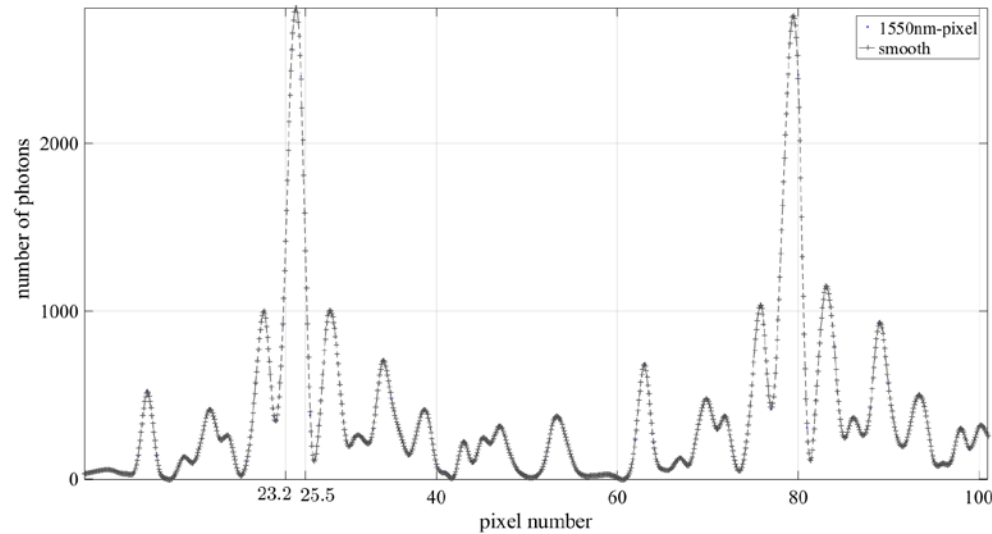


R=100,000

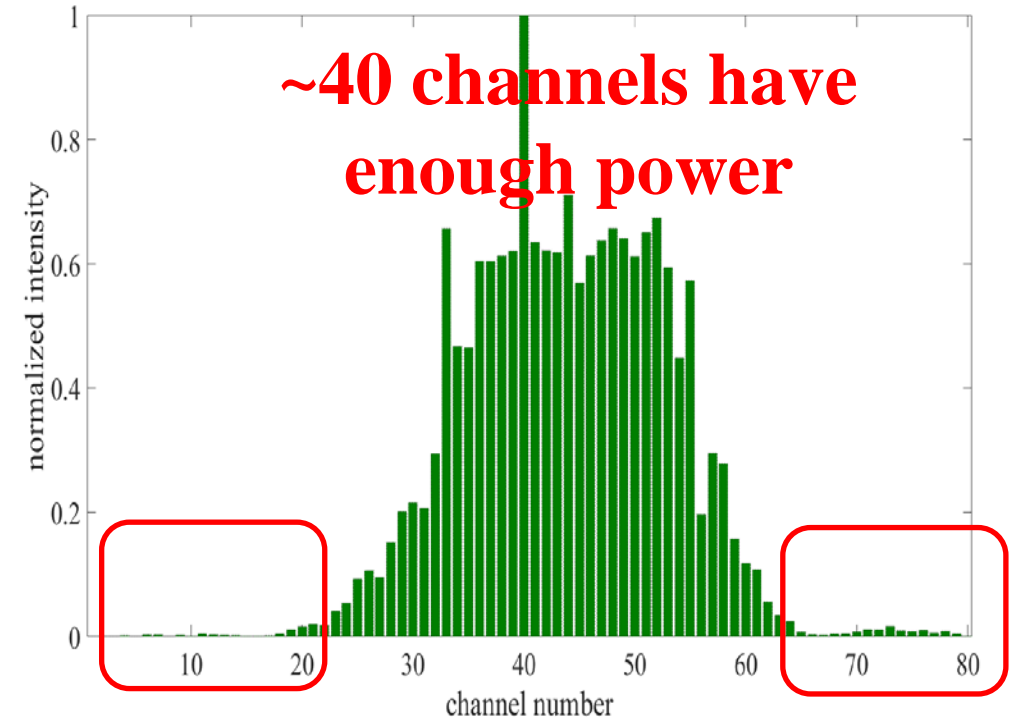
Cascaded phase modulation



Spectroscopic characteristics of the chip



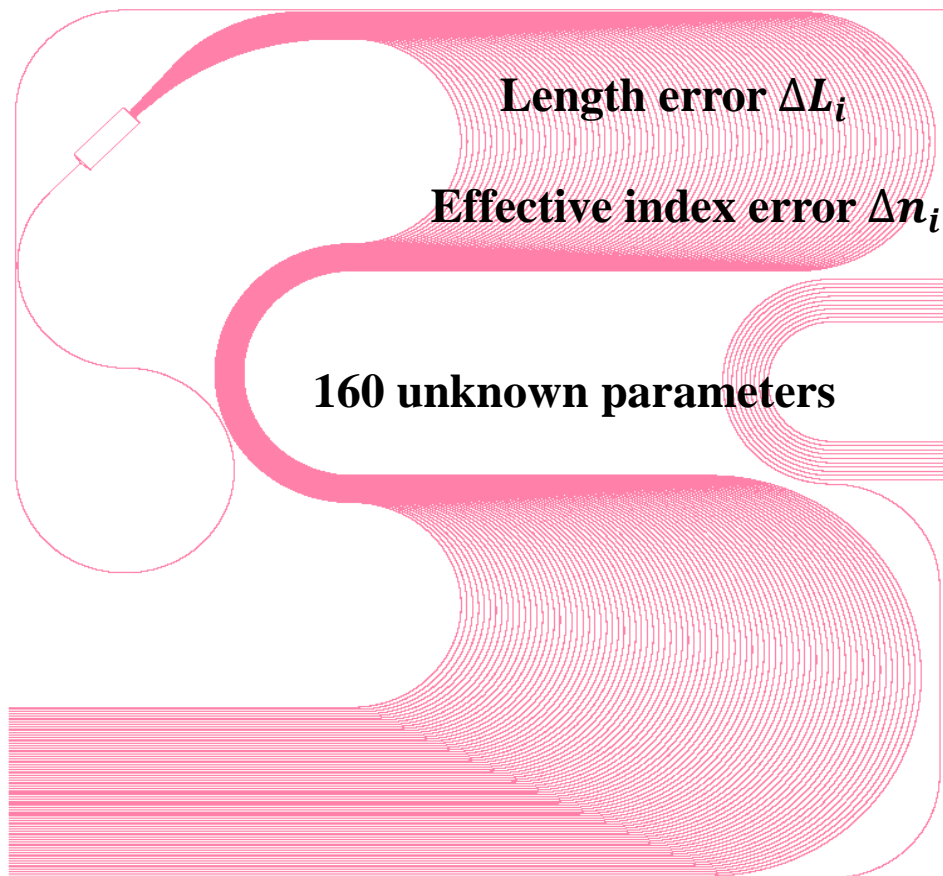
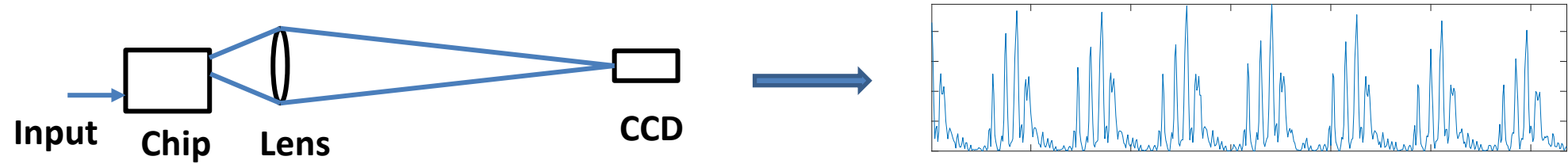
Resolution: 60784 @ 1550 nm



**75 channels have light
Fabrication is not good enough**

Low contrast due to phase error!

Spectrum Correction: Methods

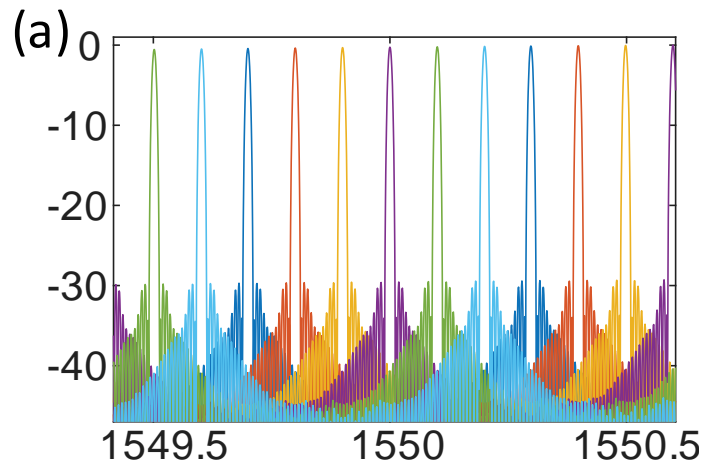


Solve for 160 unknown parameters

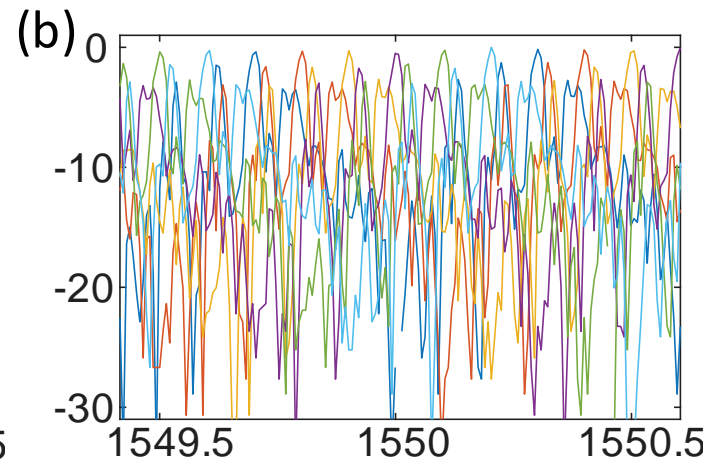
1. Construct a light transmission model
2. Measure the low-contrast spectrum under different wavelengths: 1542-1560 nm, step size: 0.1 nm, 160 measurements in total
3. Solve equations for 160 unknown errors

Remove errors and reconstruct spectrum

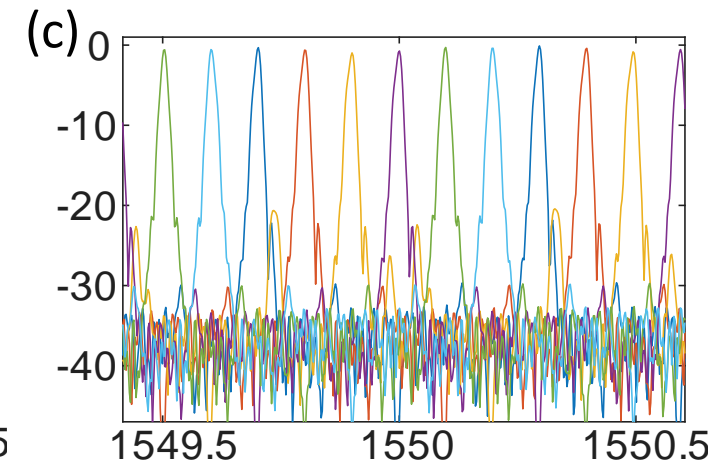
Results of spectrum correction



Ideal spectrum



Measured spectrum



Corrected spectrum

Contrast up to **20dB** after spectrum correction

Outline



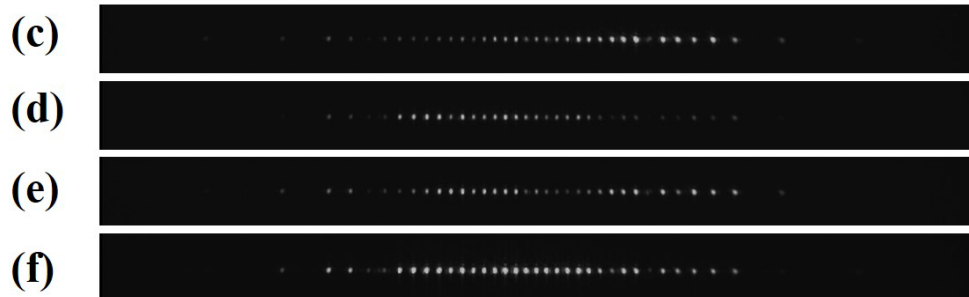
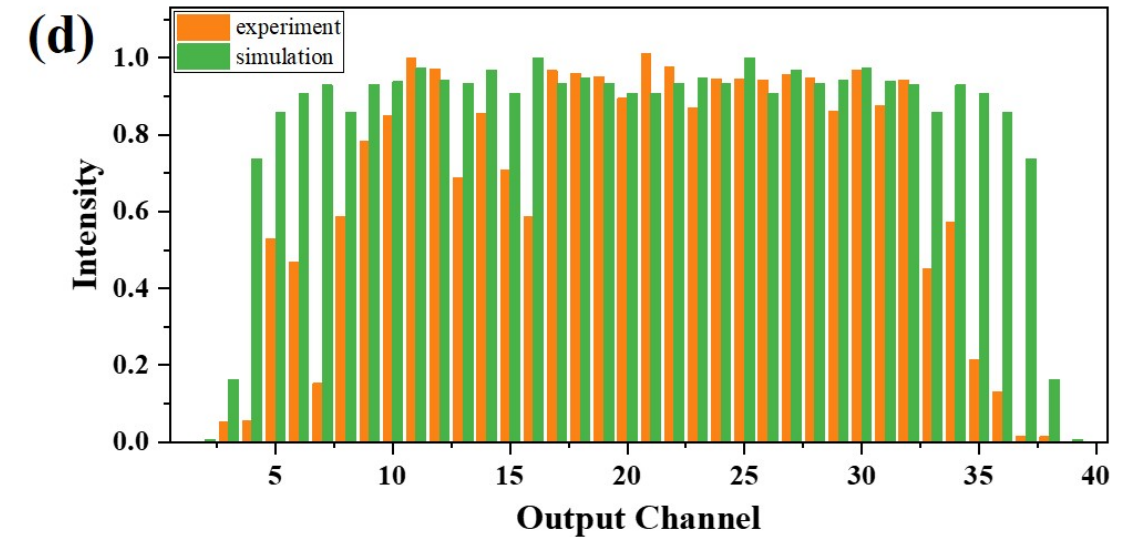
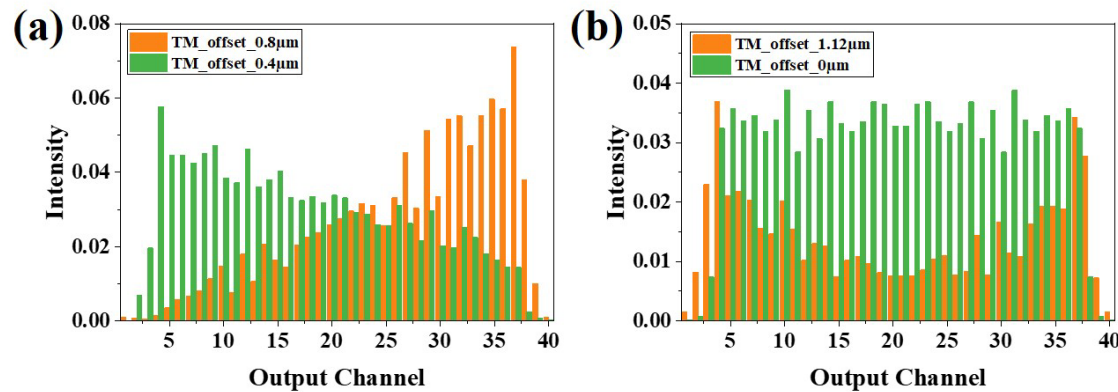
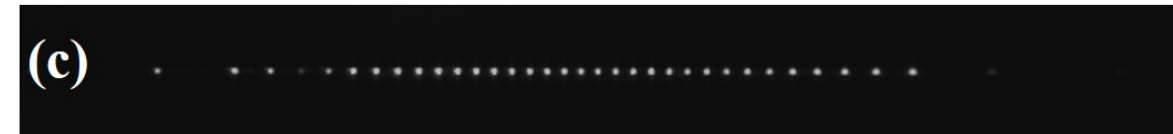
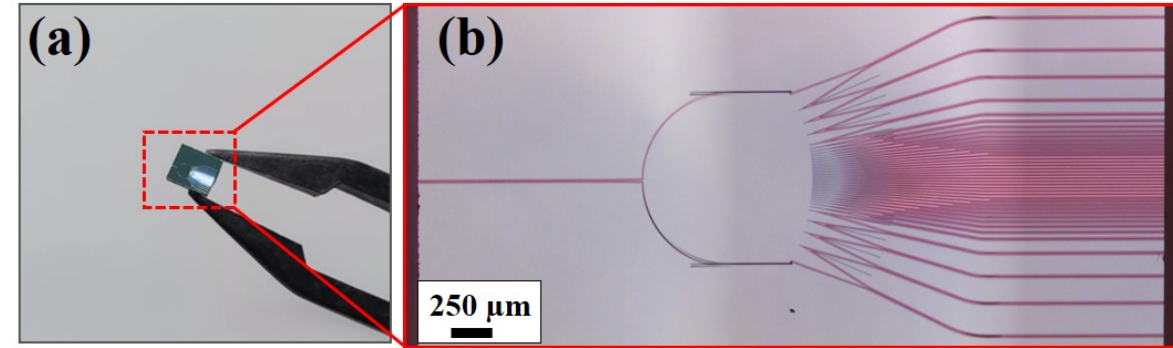
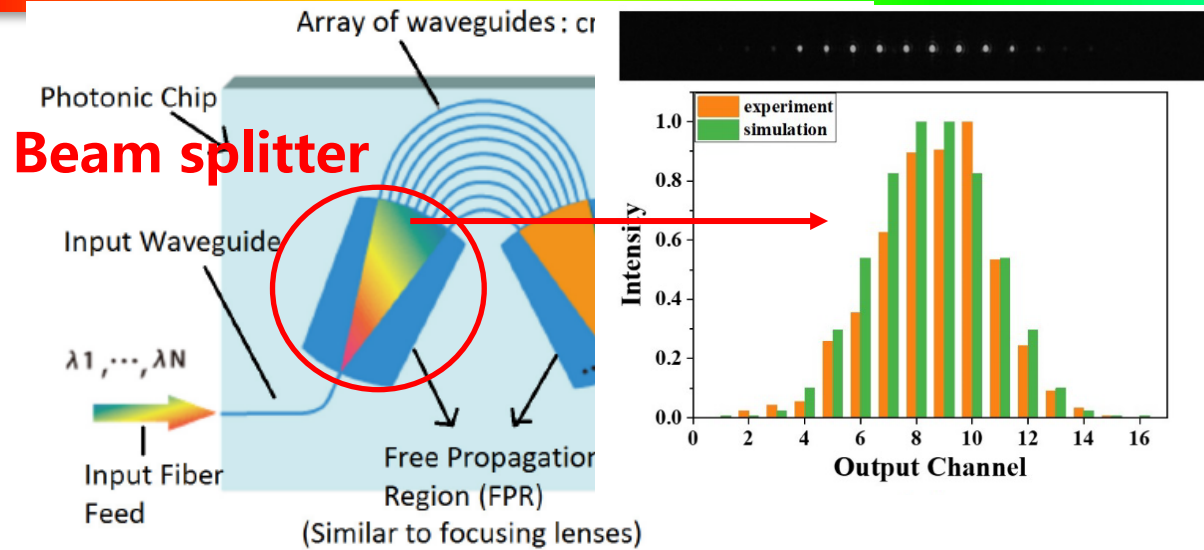
1. Background

2. High resolution waveguide array
spectroscopic chip

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4. Conclusion and prospective

Flat type beam splitter chip



Laser & Photonics Reviews,
submitted, minor revision

Outline

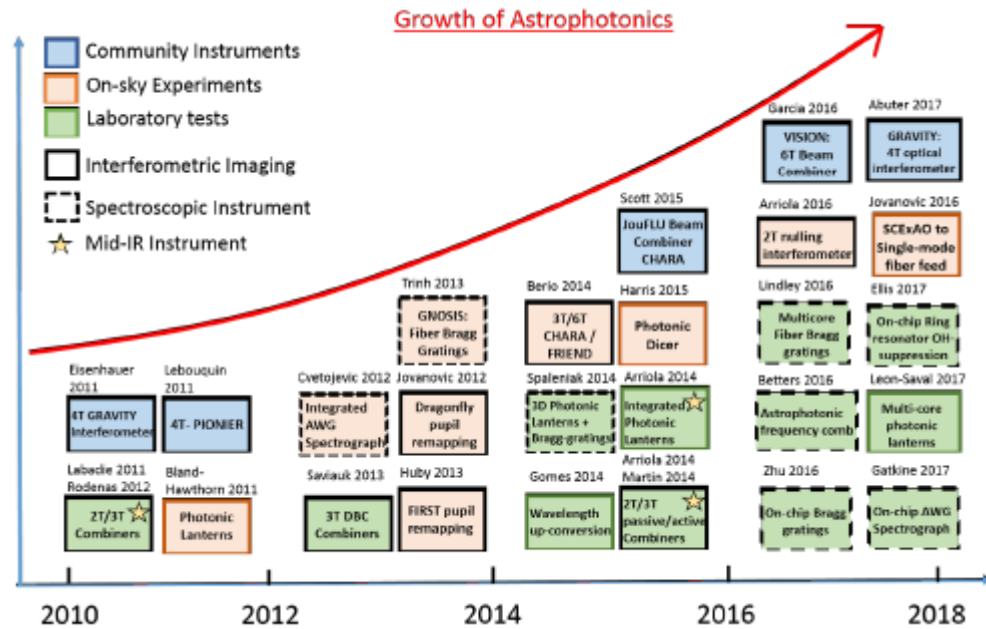


1. Background
2. High resolution waveguide array spectroscopic chip
3. Flat type beam splitter chip
4. **Conclusion and prospective**

Conclusion

- 1. High resolution chip - waveguide array with cascaded phase modulation, resolution : ~60,000**
- 2. A method to correct spectrum and enhance the contrast by ~20 dB**
- 3. Flat type beam splitter chip**

Astrophotonics -- Future of astronomical optics



美国国家科学院天文学与天体物理学十年规划

Astro 2020 State of the Profession: Astrophotonics White Paper

2023 Astrophotonics Roadmap: pathways to realizing multi-functional integrated astrophotonic instruments

Nemanja Jovanovic^{1,56,57}, Pradip Gatine^{1,56,57}, Narsireddy Anugu², Rodrigo Amezcua-Correa³, Ritoban Basu Thakur^{10,50}, Charles Beichman⁴, Chad Bender⁵, Jean-Philippe Berger⁶, Azzurra Bigioli⁷, Joss Bland-Hawthorn⁸, Guillaume Bourdarot⁹, Charles M. Bradford¹⁰, Ronald Broeke¹¹, Julia Bryant⁸, Kevin Bundy¹², Ross Cheriton¹³, Nick Cvetojevic¹⁴, Momen Diab¹⁵, Scott A. Diddams¹⁶, Aline N. Dinkelaker¹⁷, Jeroen Duis¹⁸, Stephen Eikenberry³, Simon Ellis¹⁹, Akira Endo²⁰, Donald F. Figer²¹, Michael Fitzgerald²², Itandehui Gris-Sanchez²³, Simon Gross²⁴, Ludovic Grossard²⁵, Olivier Guyon^{5,26,27,28}, Sebastiaan Y. Haffert⁵, Samuel Halverson¹⁰, Robert J. Harris^{29,30}, Jinping He^{31,32}, Tobias Herr³³, Philipp Hottinger³⁴, Elsa Huby³⁵, Michael Ireland³⁶, Rebecca Jenson-Clem¹², Jeffrey Jewell¹⁰, Laurent Jocou³⁷, Stefan Kraus³⁸, Lucas Labadie³⁹, Sylvestre Lacour³⁵, Romain Laugier⁷, Katarzyna Ławniczuk¹¹, Jonathan Lin²², Stephanie Leifer⁴⁰, Sergio Leon-Saval⁸, Guillermo Martin³⁷, Frantz Martinache¹⁴, Marc-Antoine Martinod⁷, Benjamin A. Mazin⁴¹, Stefano Minardi⁴², John D. Monnier⁴³, Reinan Moreira⁴⁴, Denis Mourard¹⁴, Abani Shankar Nayak⁴⁵, Barnaby Norris⁸, Ewelina Obrzud⁴⁶, Karine Perraut³⁷, François Reynaud²⁵, Steph Sallum⁴⁷, David Schiminovich⁴⁸, Christian Schwab⁴⁹, Eugene Serbayn¹⁰, Sherif Soliman¹⁸, Andreas Stoll¹⁷, Liang Tang^{31,32}, Peter Tuthill⁸, Kerry Vahala⁵⁰, Gautam Vasisht¹⁰, Sylvain Veilleux⁵¹, Alexander B. Walter¹⁰, Edward J. Wollack⁵², Yinzi Xin¹, Zongyin Yang⁵³, Stephanos Yerolatsitis³, Yang Zhang⁵⁴ and Chang-Ling Zou⁵⁵.

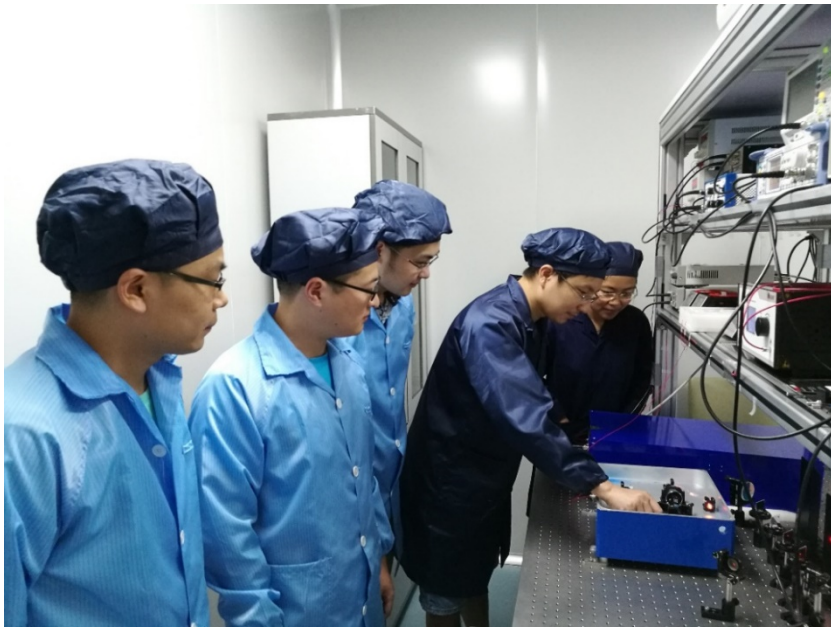
Lead by Caltech, 80 researchers, 55 organizations, 12 countries

Jinping He / 何晋平

Tel/Wechat: 15062217436

Email: jphe@niaot.ac.cn

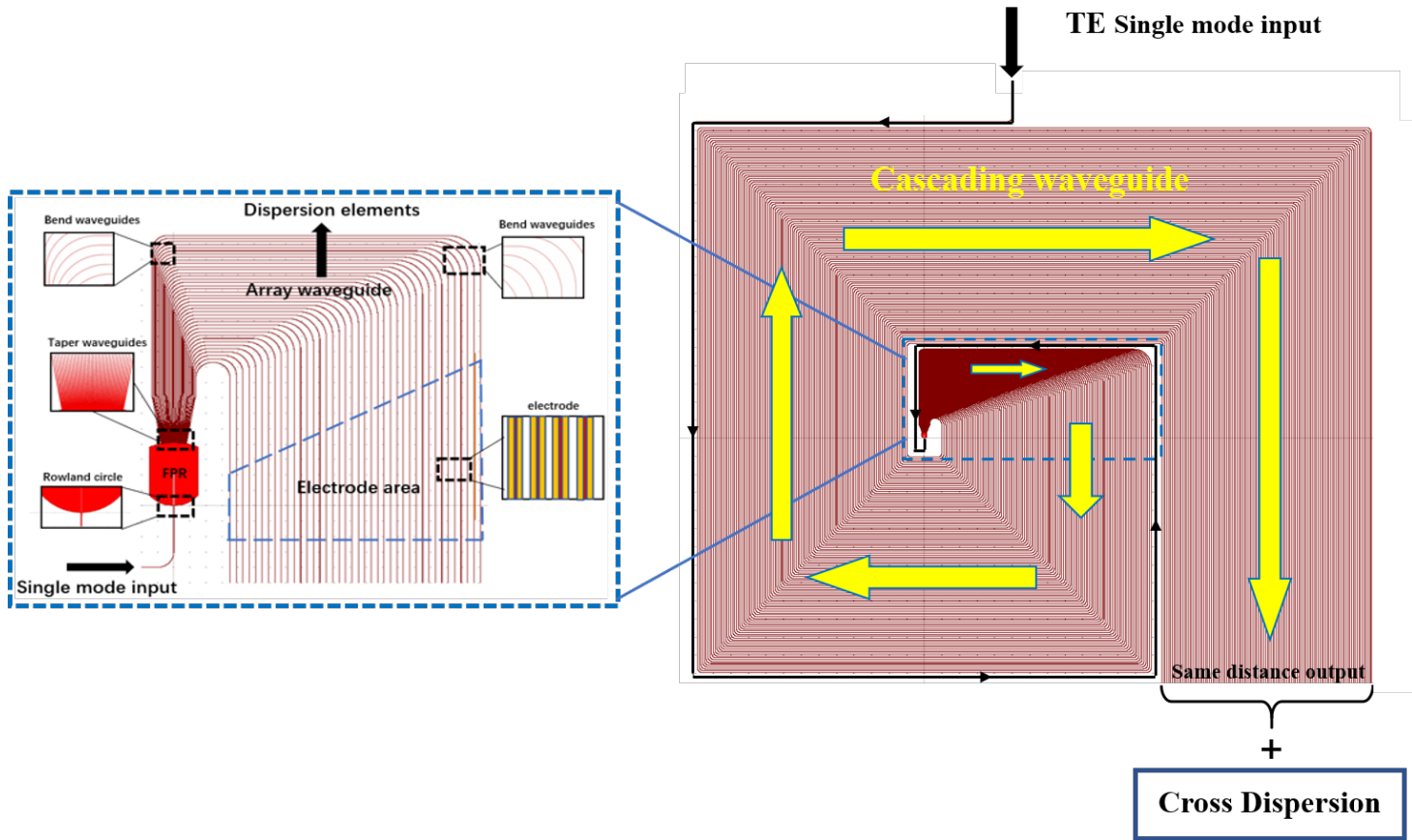
Thanks !



Any discussion or cooperation is welcome

How to decrease phase error

■ Active compensation

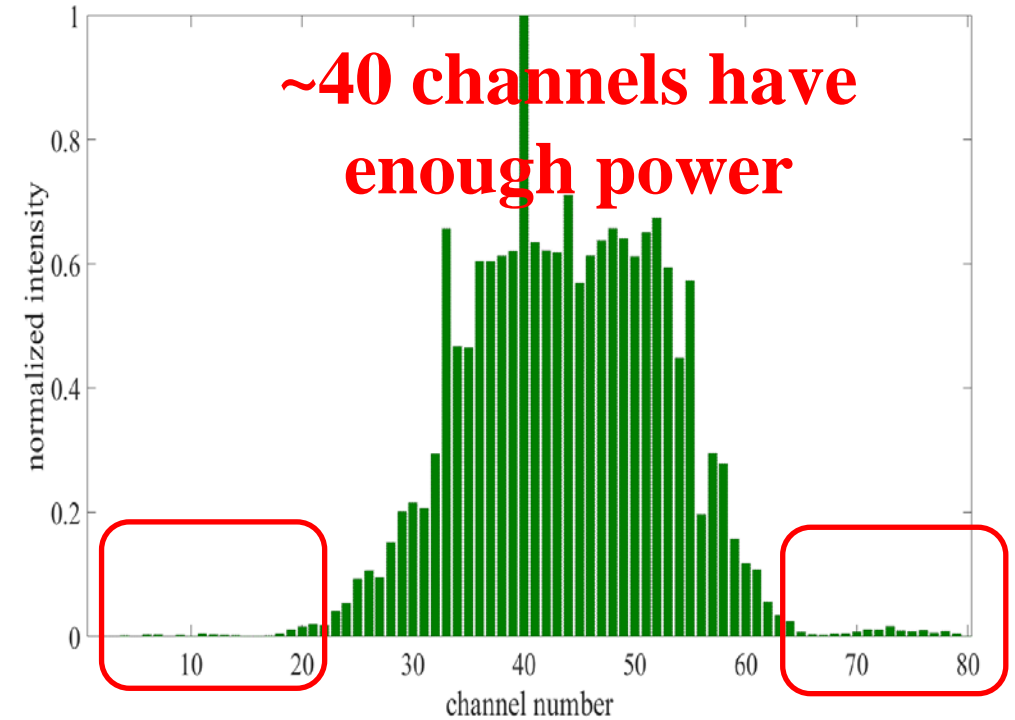
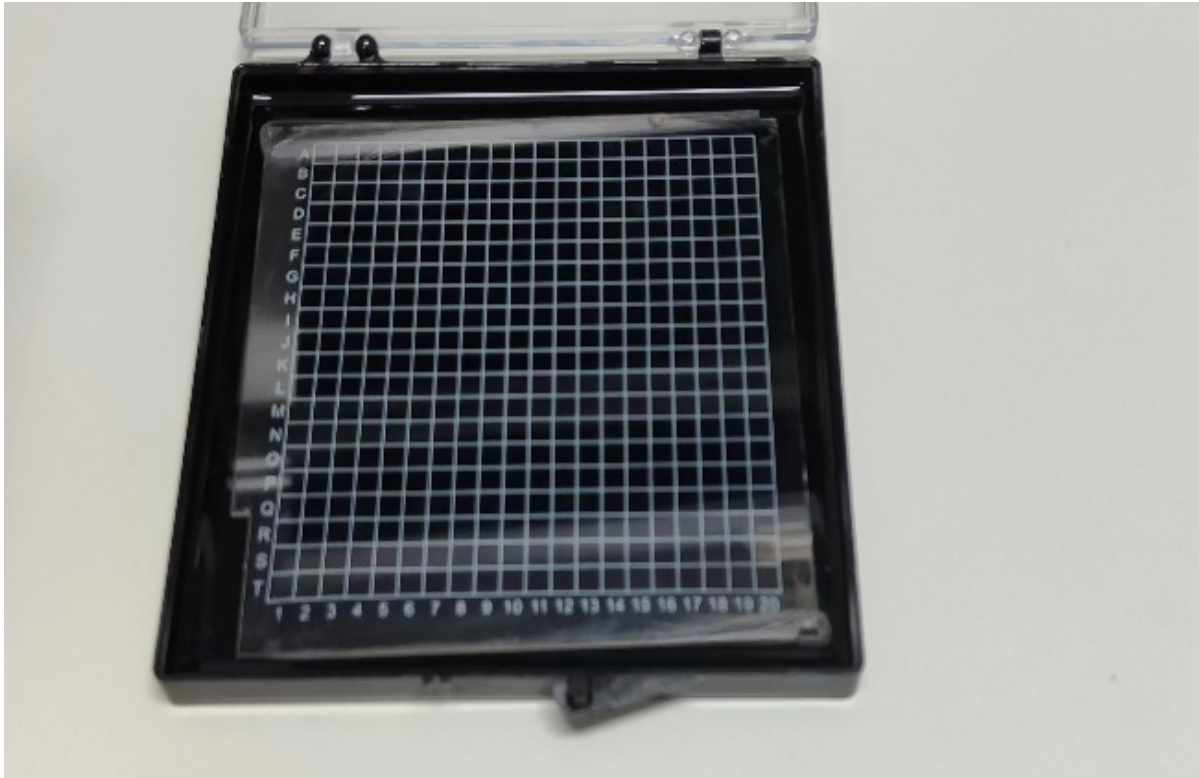


Lithium niobate -- Electro-optic modulation

■ Ultra-high precise fabrication



Chip and its output



Waveguide array with cascaded phase modulation

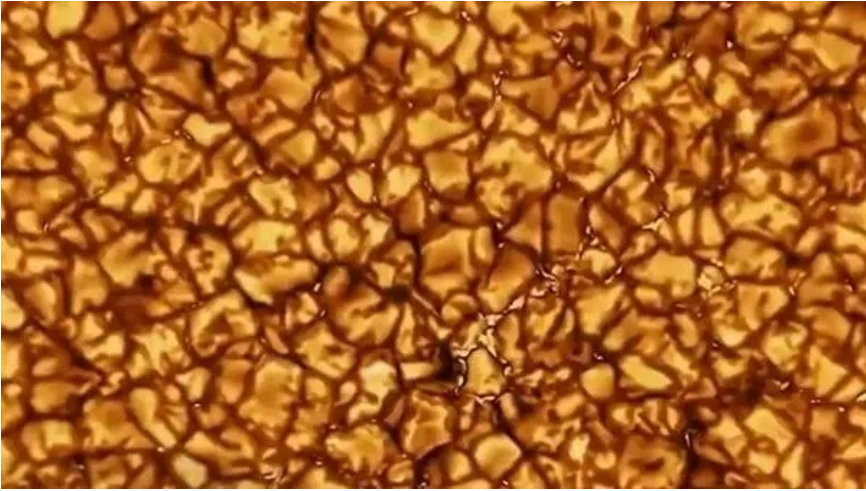
Resolution : 100,000@1550nm

Size : 10.3 cm*10.4 cm

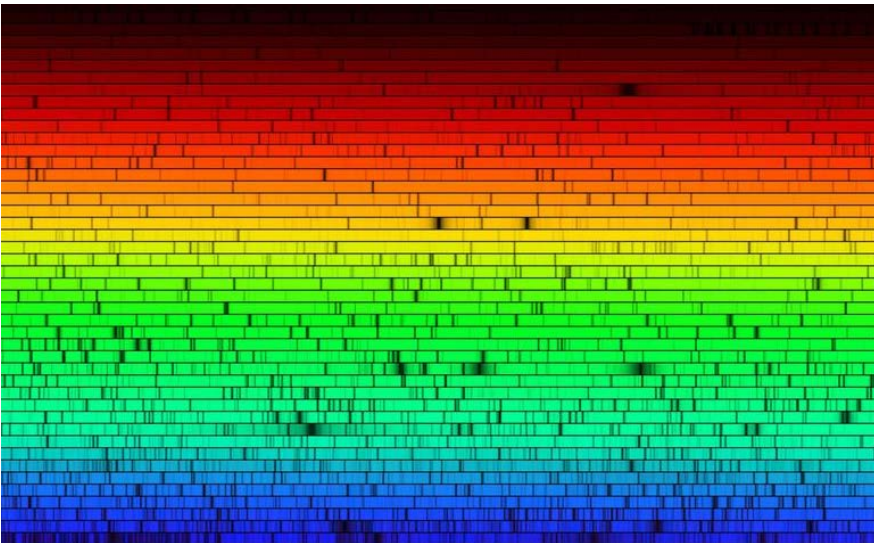
75 channels have light

Fabrication is not good enough

Main observation methods of astronomy

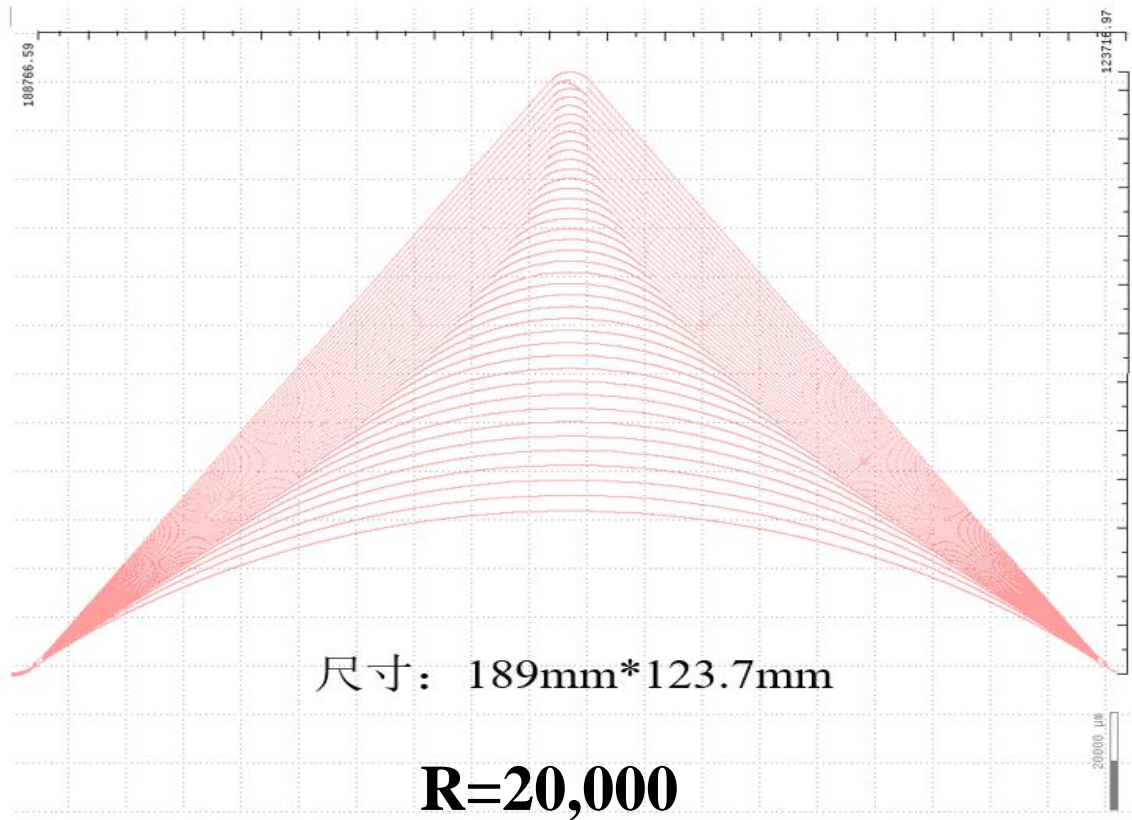


Imaging : structure

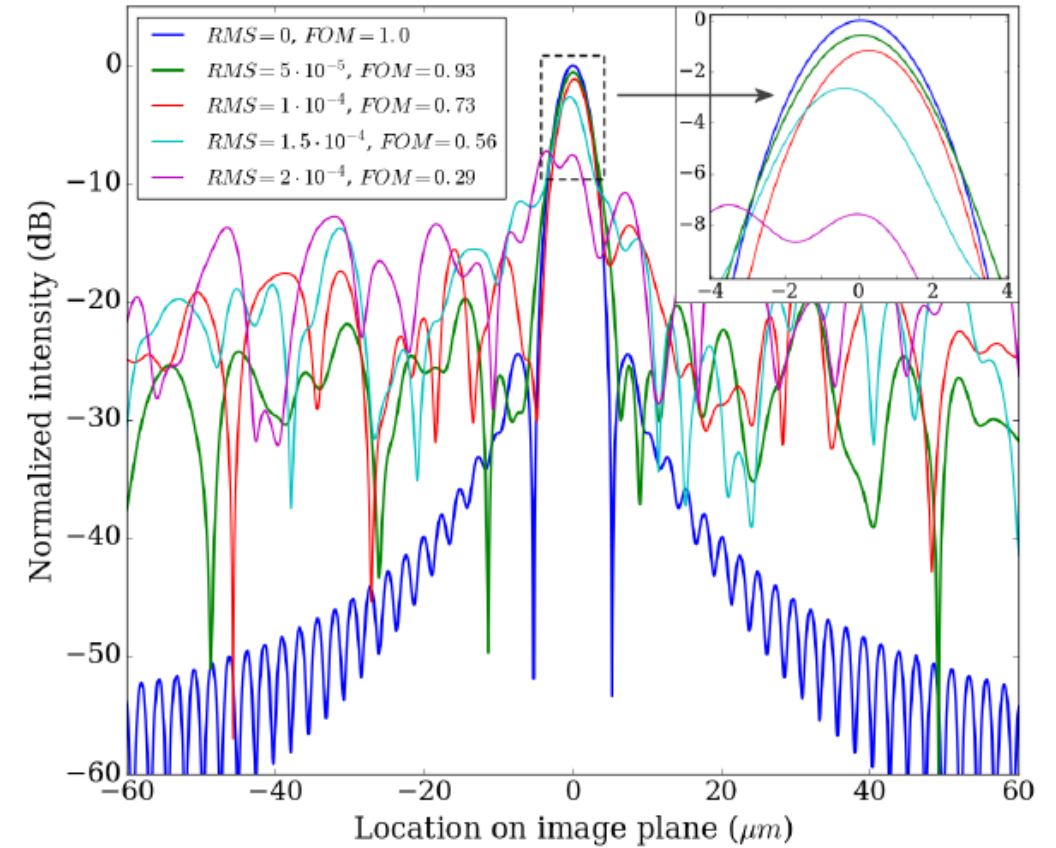


**Spectroscopy : physical
and chemical properties**

Challenges for high resolution spectroscopic chip



Common AWG structure -- large scale



Phase error due to fabrication