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MULTI-LASER-WIRE DIAGNOSTIC FOR THE BEAM PROFILE MEASUREMENT OF NEGATIVE HYDROGEN ION BEAM IN THE J-PARC LINAC

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Contents

Multi-laser-wire Diagnostic for the Beam Profile Measurement of Negative Hydrogen Ion Beam in The J-PARC Linac

1. Introduction / Objective

Laser-wire profile monitor

- Beam profile monitor plays am important role in the he high-current and high-brilliance accelerators.
- To avoid the thermal damage of the metallic wire scanner monitor and to reduce the radiation during an operation, the laser-wire method is the possible candidate for the profile measurement.
- The photon energy with only 0.75 eV is required for the photo detachment to generate H^0 from H^-.

Multi-laser-wire

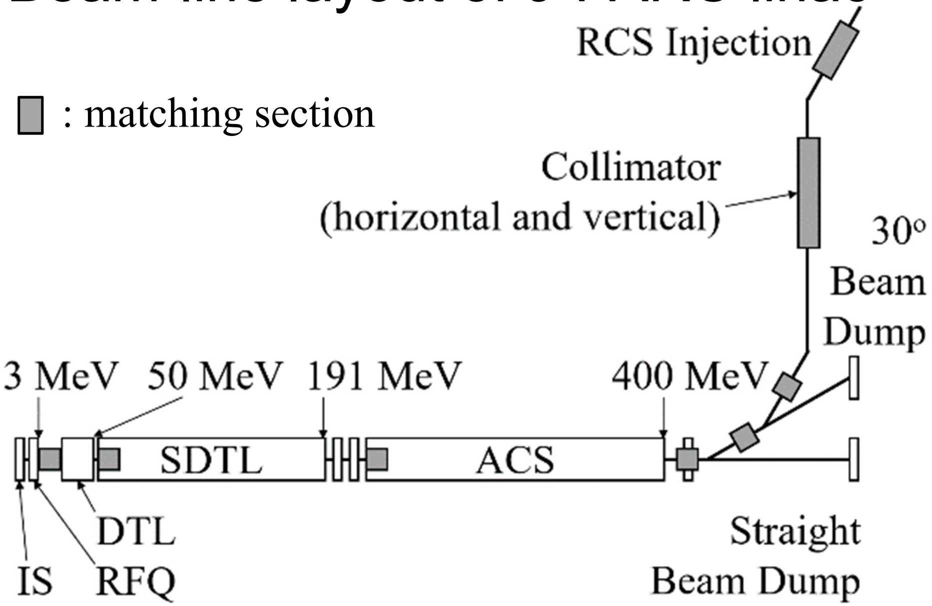
- A simple optical design with only a pair of concave mirrors brings the multi-laser paths.
- No scanning device and no multiple-shots of the accelerated beams are required for the system.

Objective of the study

- To design the system for the J-PARC linac, the feasibility check and the demonstration of the multi-laser-wire formation are key missions of our study.

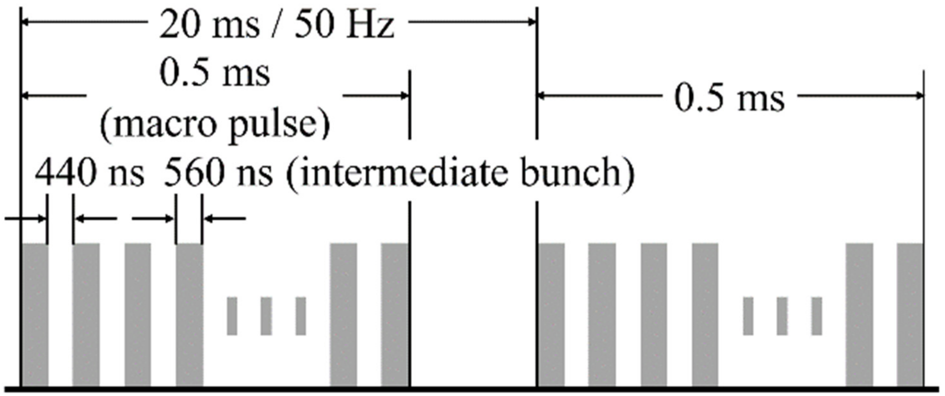
2. Beam specification of J-PARC linac

Beam-line layout of J-PARC linac



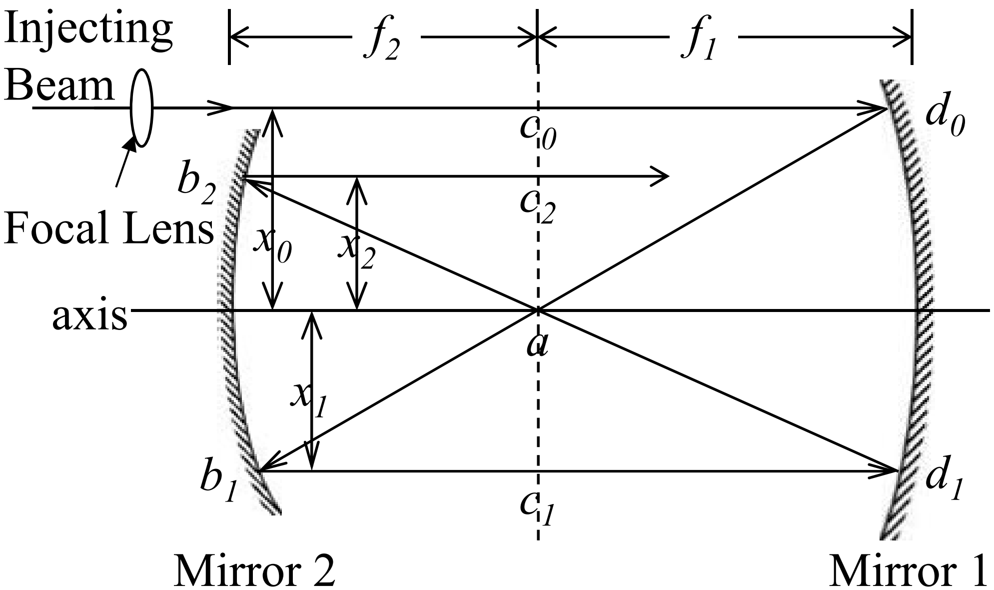
- Linac accelerates the H^- beam up to 400 MeV.
- There are 8 matching sections where the transverse matching is conducted using the wire scanner monitors.

Time structure of pulsed beam



- H^- beam is accelerated by 324 MHz RF which is the smallest time structure (3.01 ns).
- Intermediate bunch with 560 ns is for the injection to the downstream RCS.
- The longest pulse duration is 500 μs.

Asymmetrical confocal cavity



A pair of concave mirrors with different diameters to make multi-paths of laser beam, and the beam waists of the laser paths are aligned in principle.

- The distance from axis is defined as $x_0, x_1, \ldots\ldots, x_n$.

$$x_1 = \left(\frac{f_2}{f_1}\right) x_0$$

$$x_2 = \left(\frac{f_2}{f_1}\right) x_1 = \left(\frac{f_2}{f_1}\right)^2 x_0$$

$$\boxed{x_n = \left(\frac{f_2}{f_1}\right)^n x_0}$$

- The $1/e^2$ radius at $c_0, c_1, \ldots\ldots, c_n$ as $w_0, w_1, \ldots\ldots, w_n$ using a wave length (λ).

$$w_0 w_1 = \frac{\lambda f_1}{\pi}$$

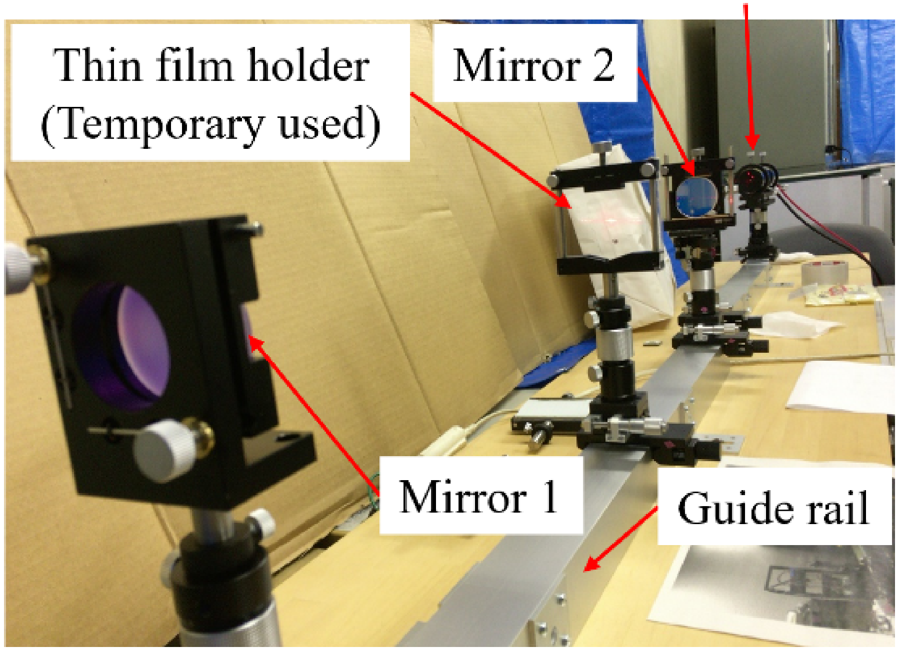
$$w_1 w_2 = \frac{\lambda f_2}{\pi} \rightleftarrows w_2 = \left(\frac{f_2}{f_1}\right) w_0$$

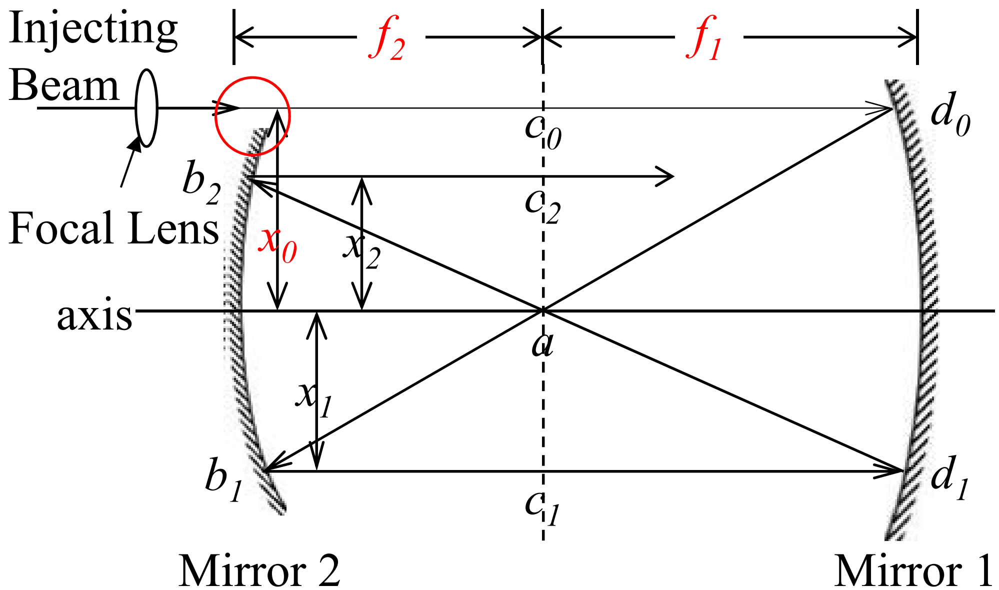
$$\boxed{w_n = \left(\frac{f_2}{f_1}\right)^{n-1} w_0}$$

4. Demonstration of the multi-laser-wire formation

Optical set-up of asymmetrical confocal cavity.

He-Ne Laser (515 nm, 2.4 eV, 300 mJ, M^2 <1.2)





- A pair of mirrors with focus length of f_1 (435 mm) and f_2 (417 mm) are used.
- Distance between the mirrors are set to 852 mm ($L = f_1+f_2$).
- We cut an edge of 2.0 mm of mirror 2, and set an offset of 25 mm from the centre axis (x_0).

4. Demonstration of the multi-laser-wire formation

Laser beam spots on film plane

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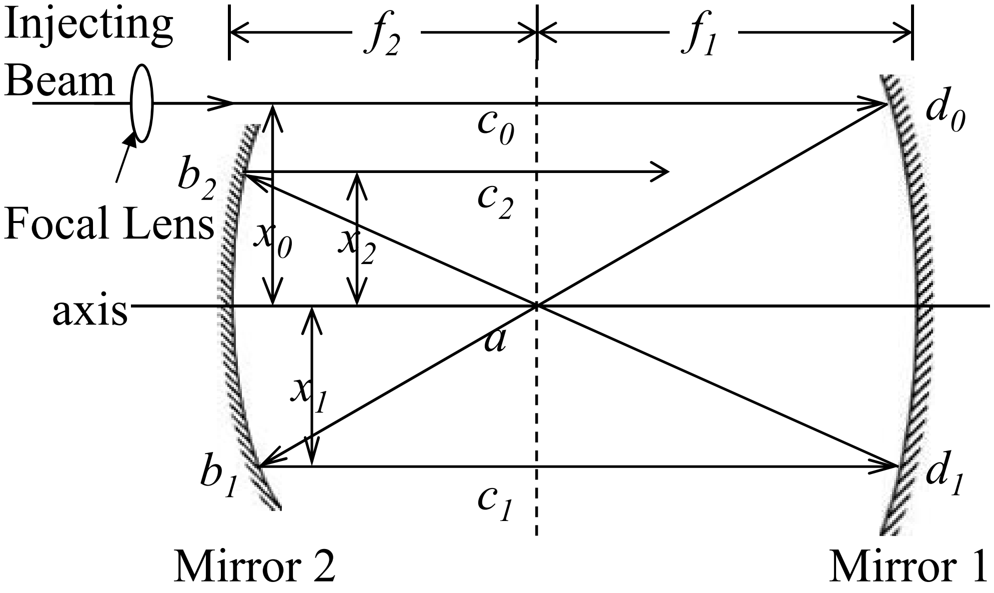

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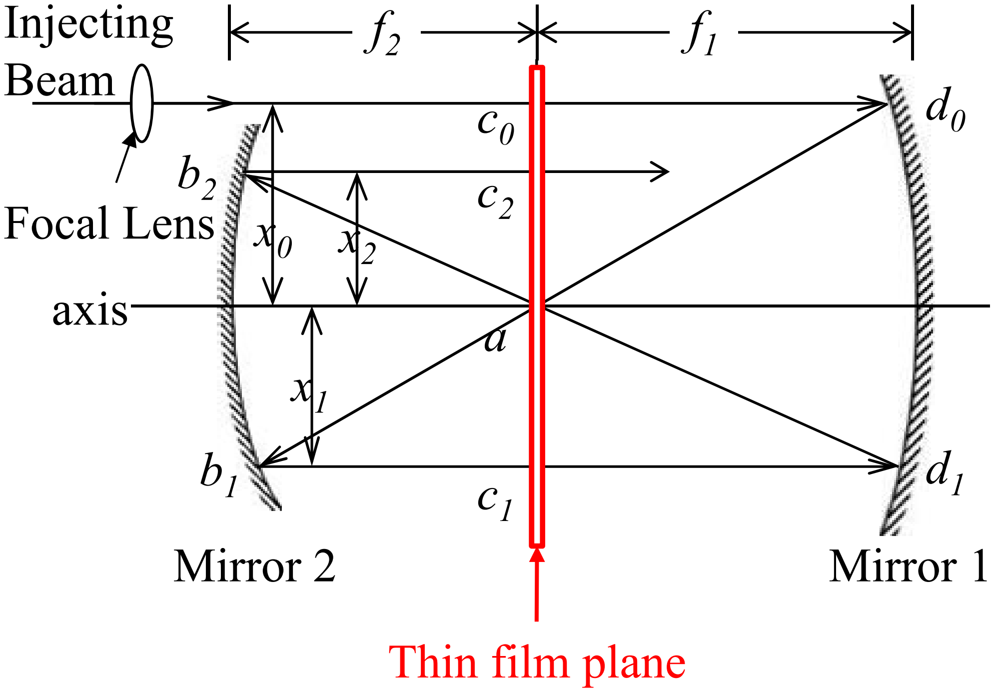

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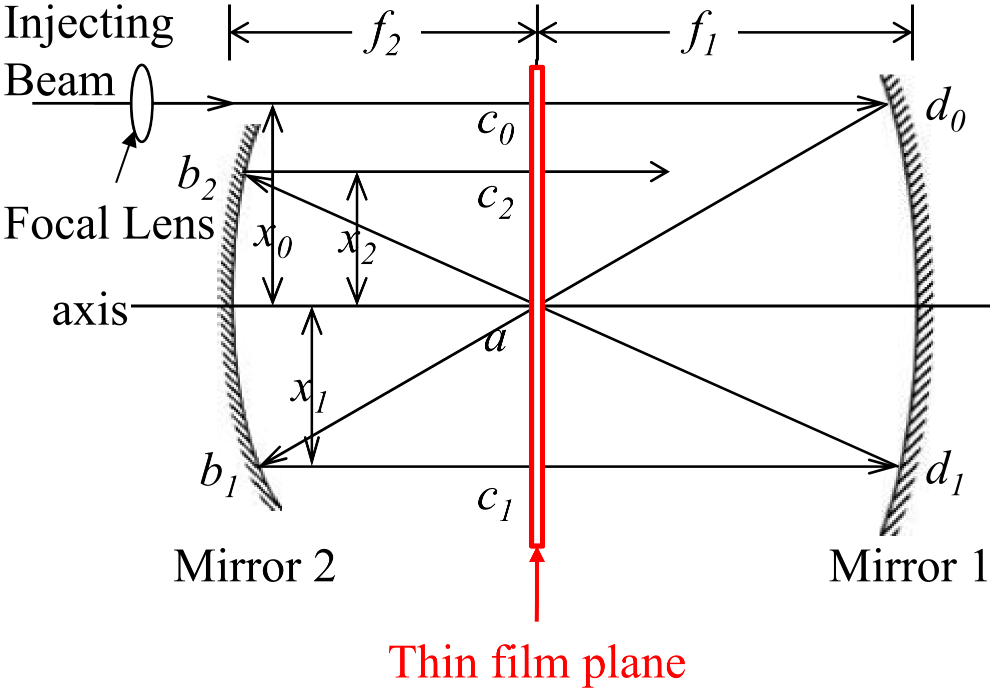

- A thin film plane is inserted to observe the laser paths.

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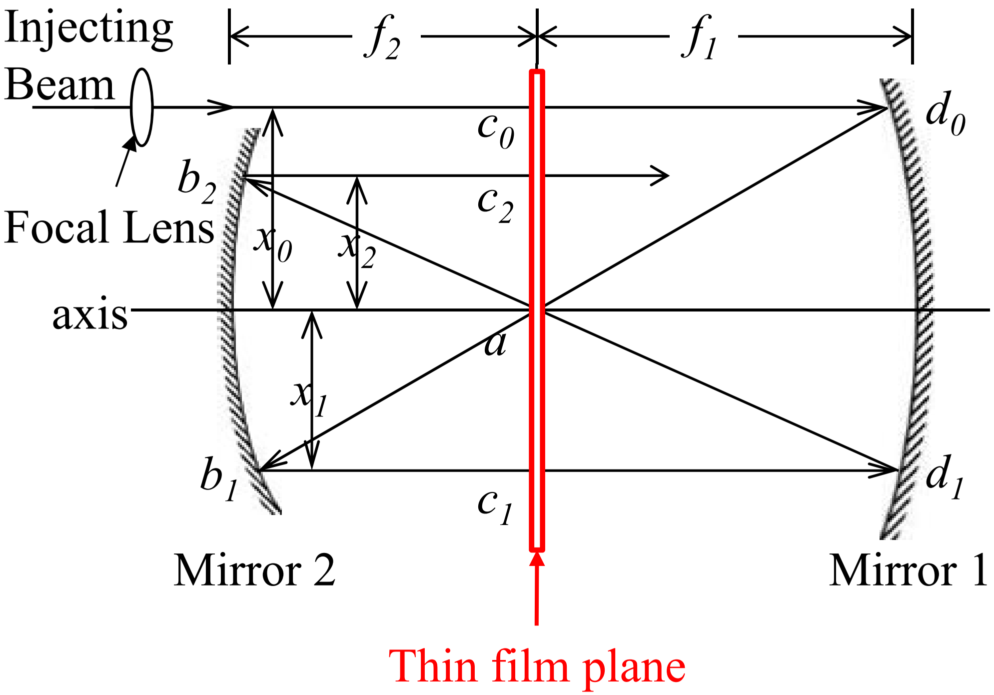

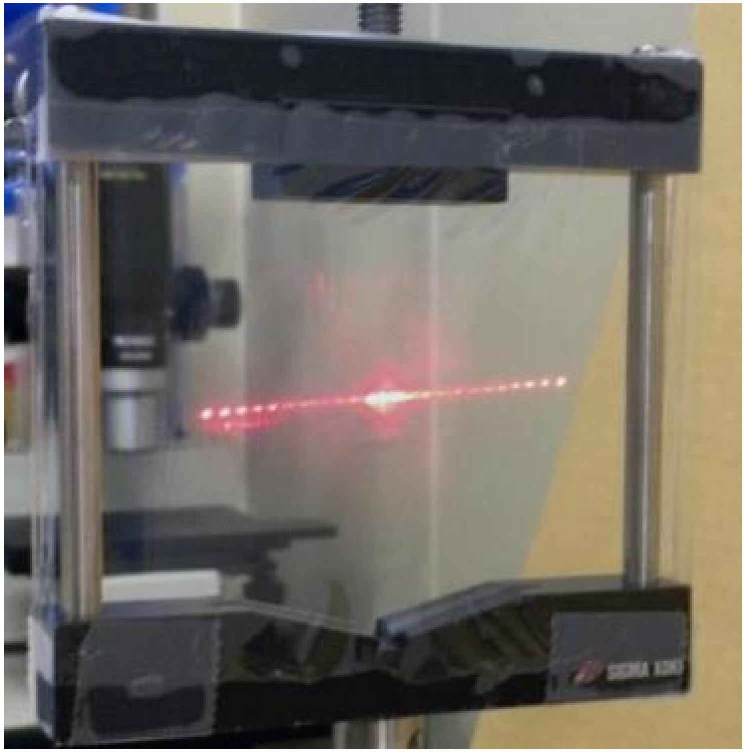

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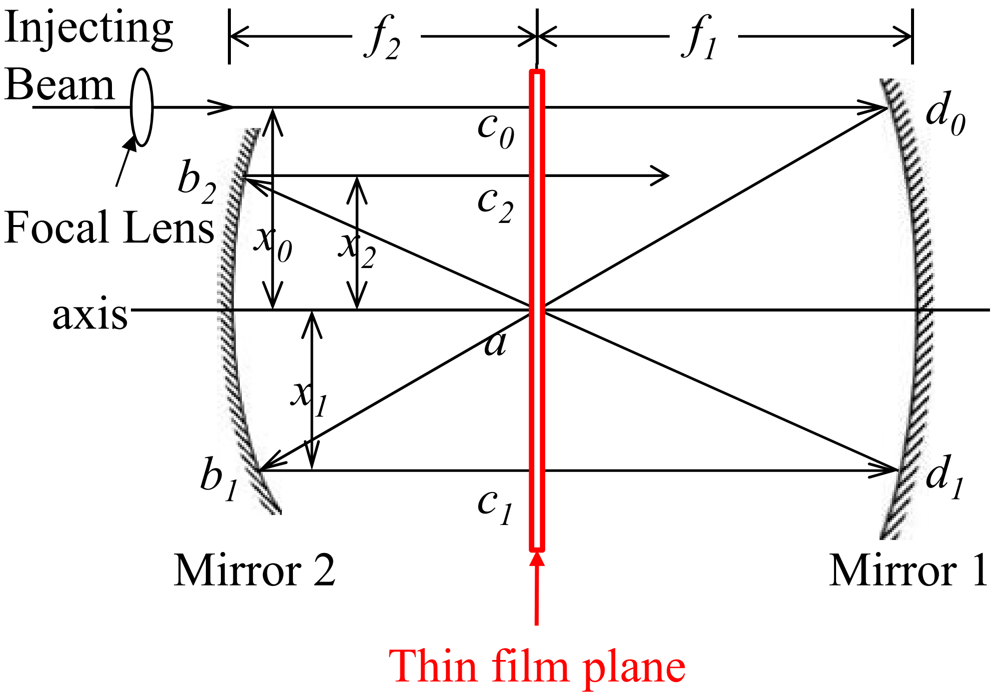

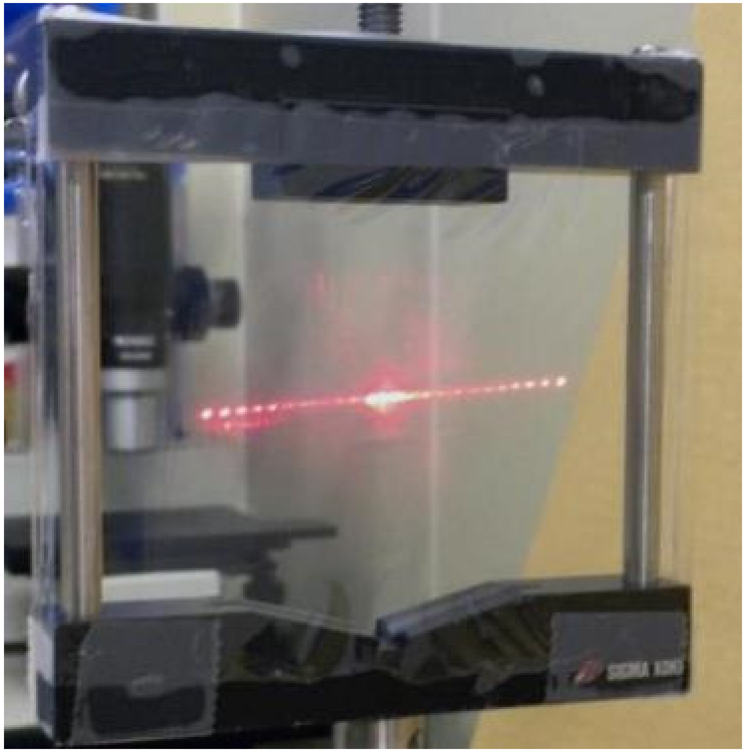

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- The laser beam spots is approaching to "*a*".

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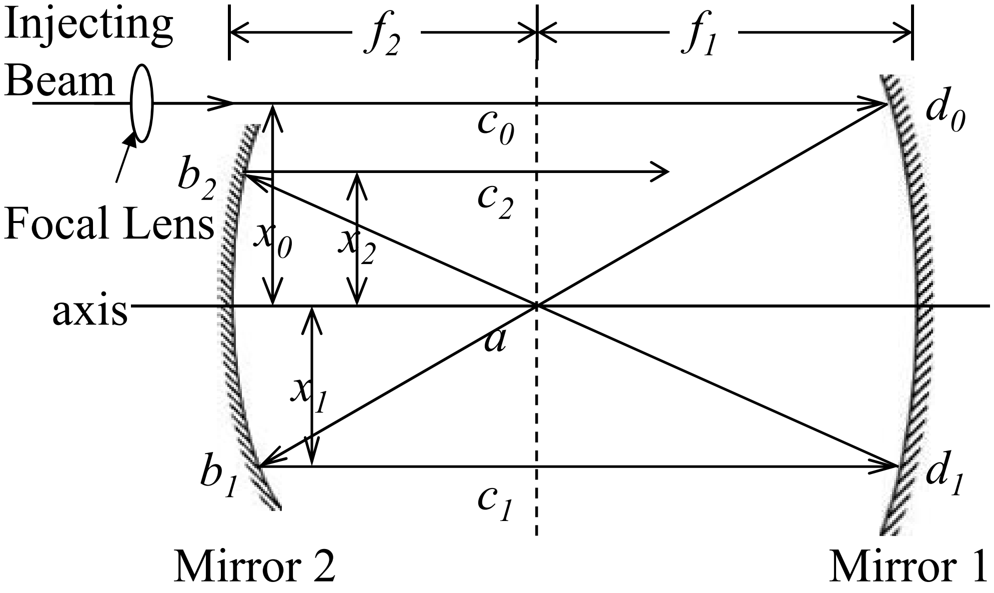

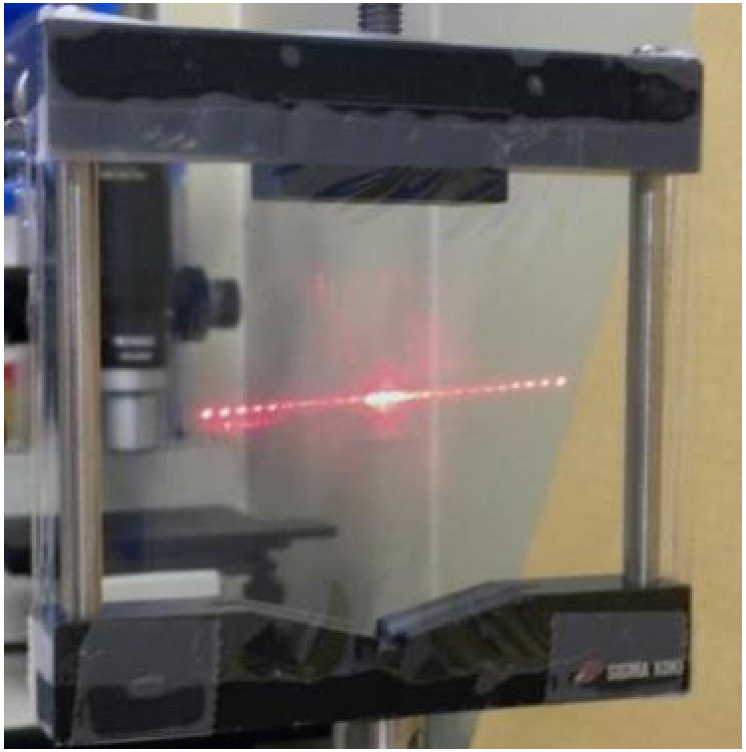

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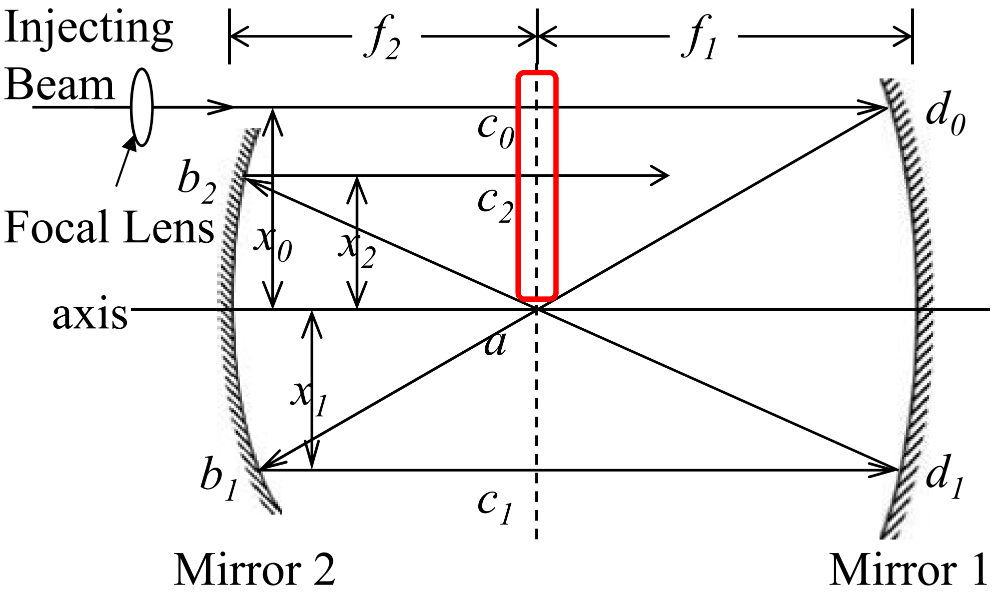

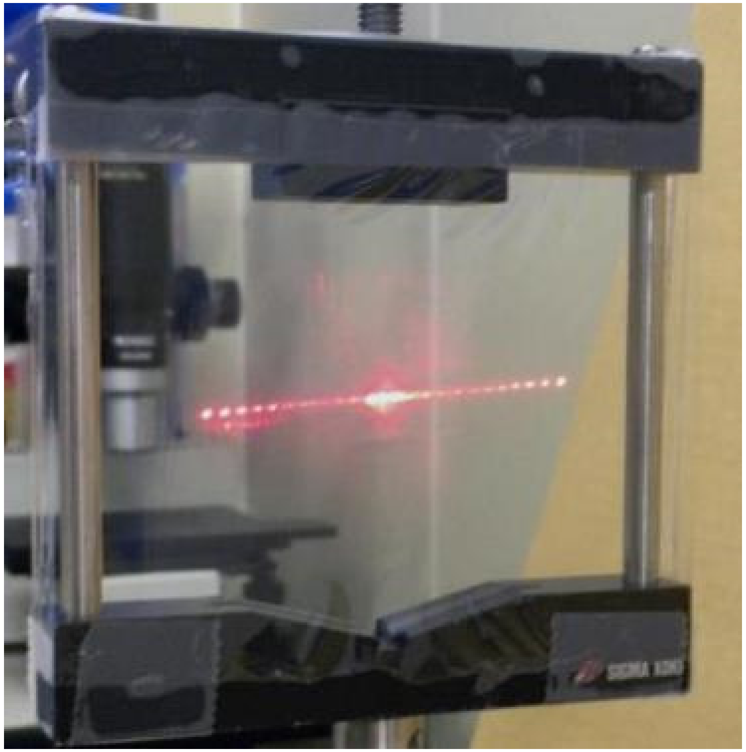

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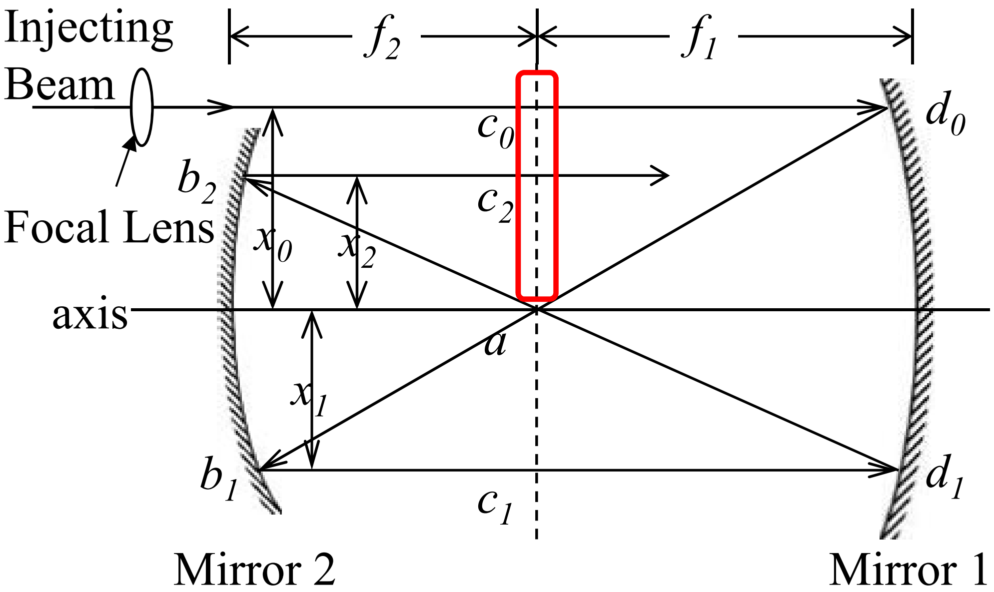

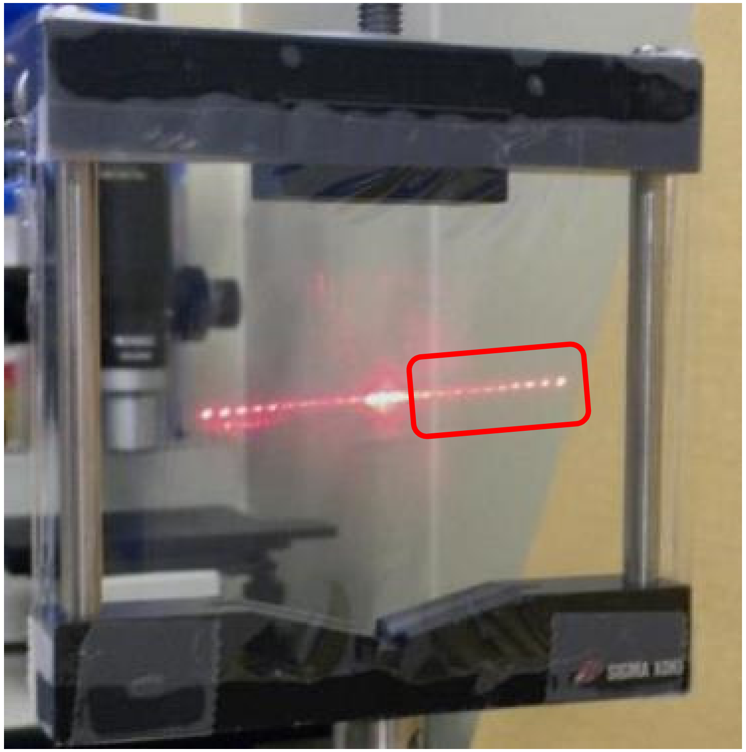

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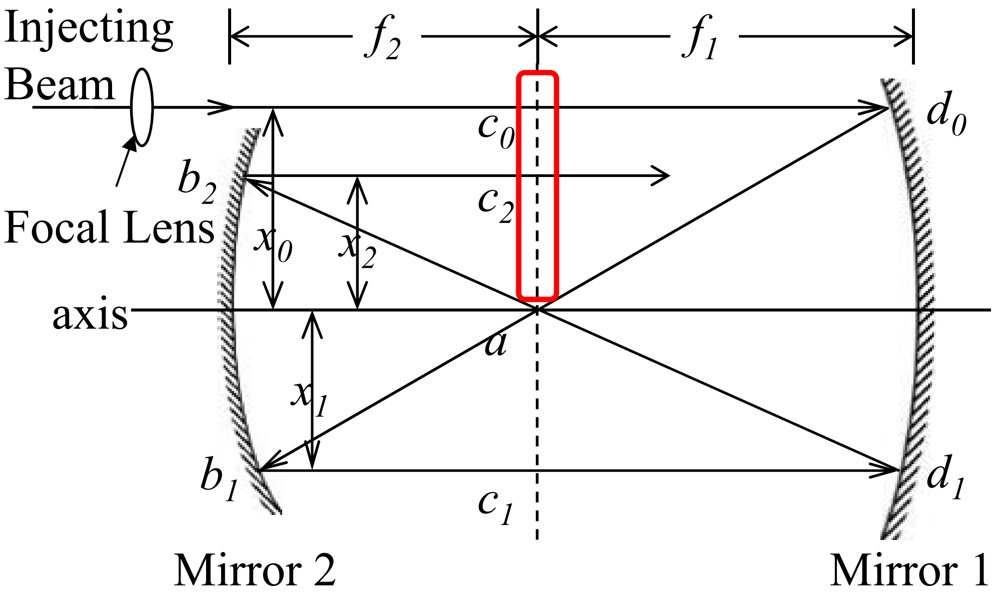

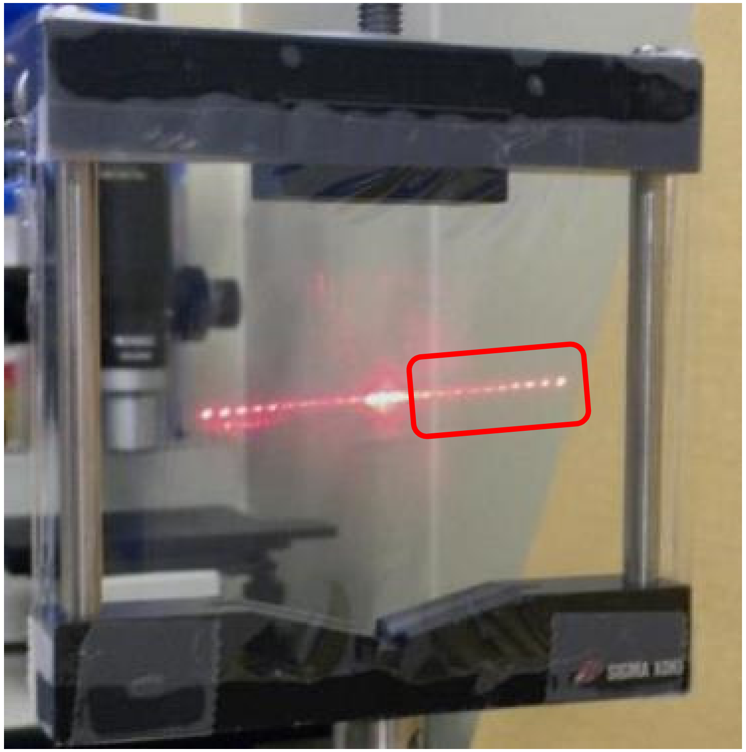

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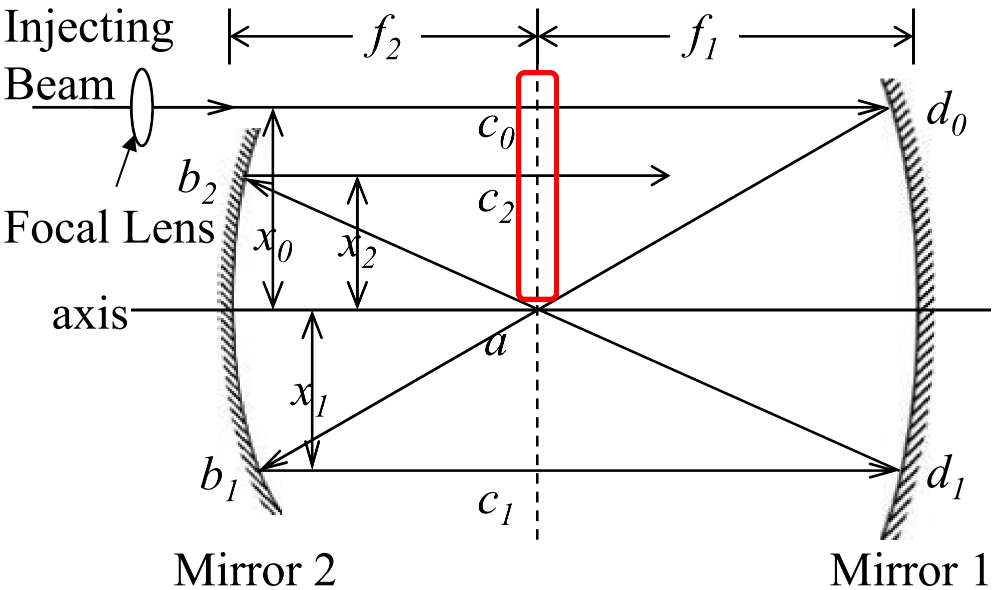

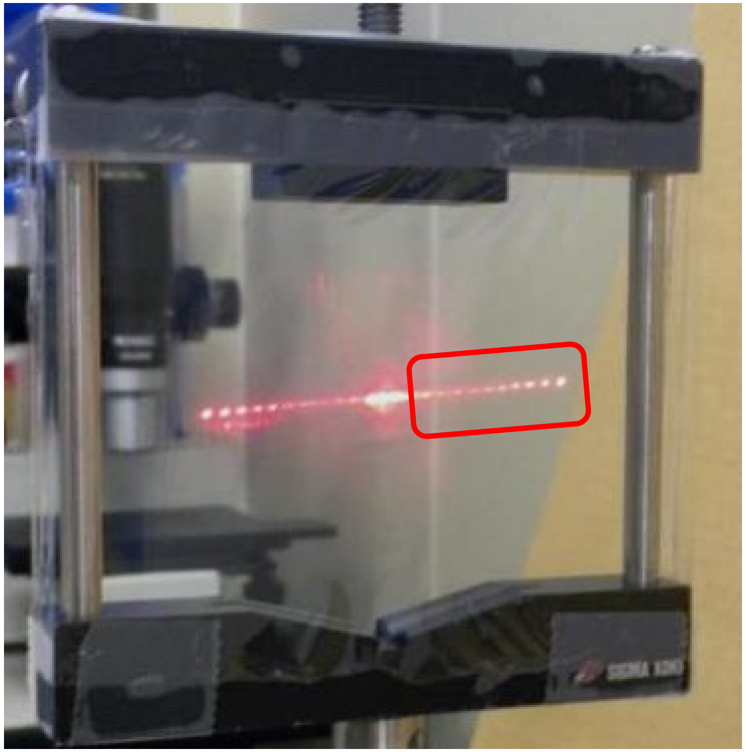

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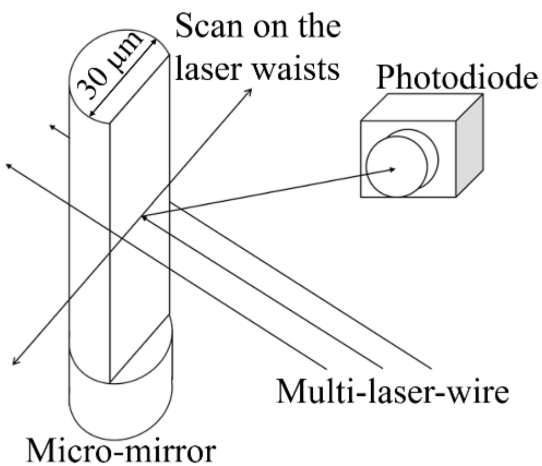
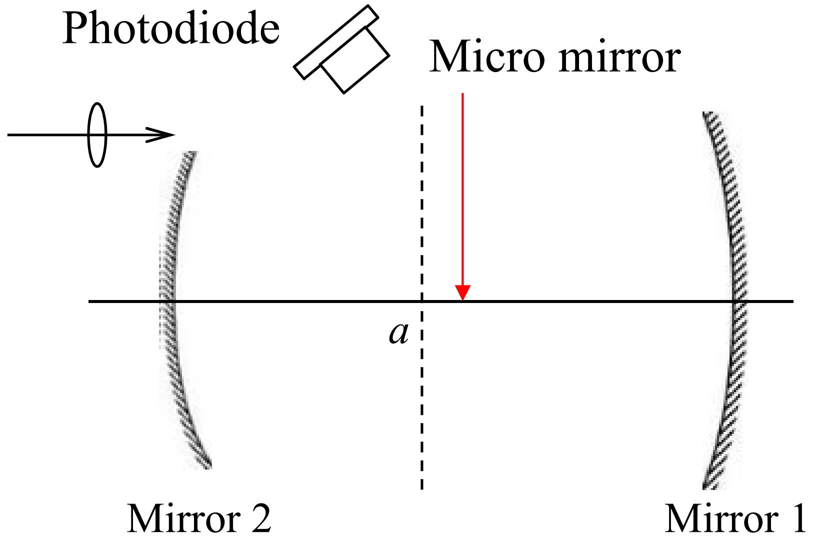
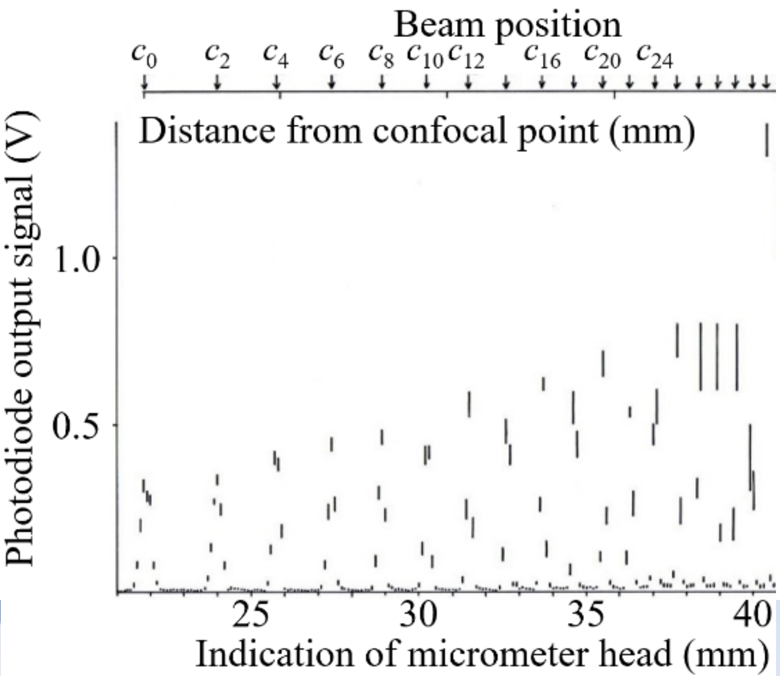
laser intensity measurement using a micro-mirror

- A micro mirror is produced by ϕ30um gold-wire with optical flat surface.
- A photodiode is used for the quantitative measurement.



- We could count 24-laser spots at the top-half of the center axis clearly.
- Spots are overlapped around the center axis.





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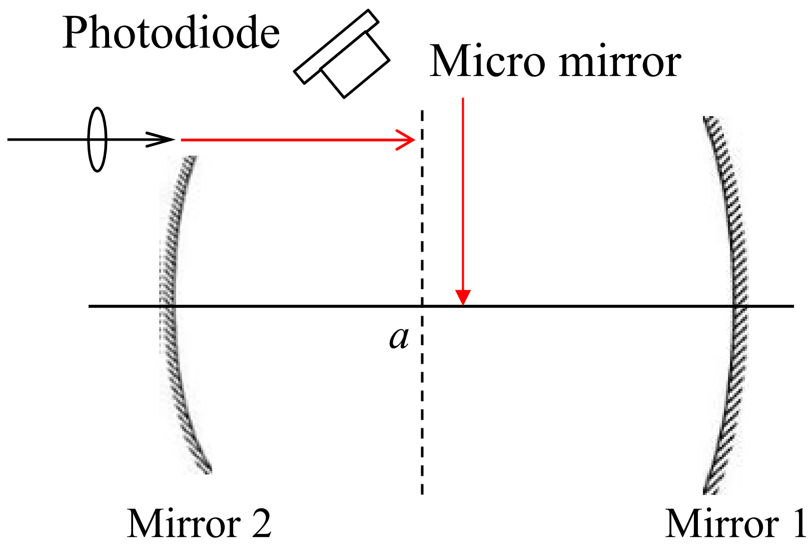

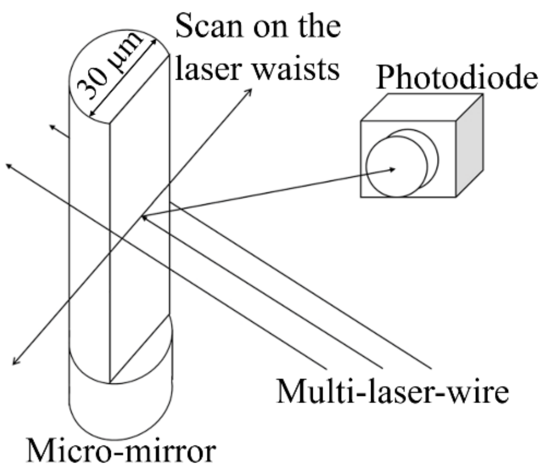

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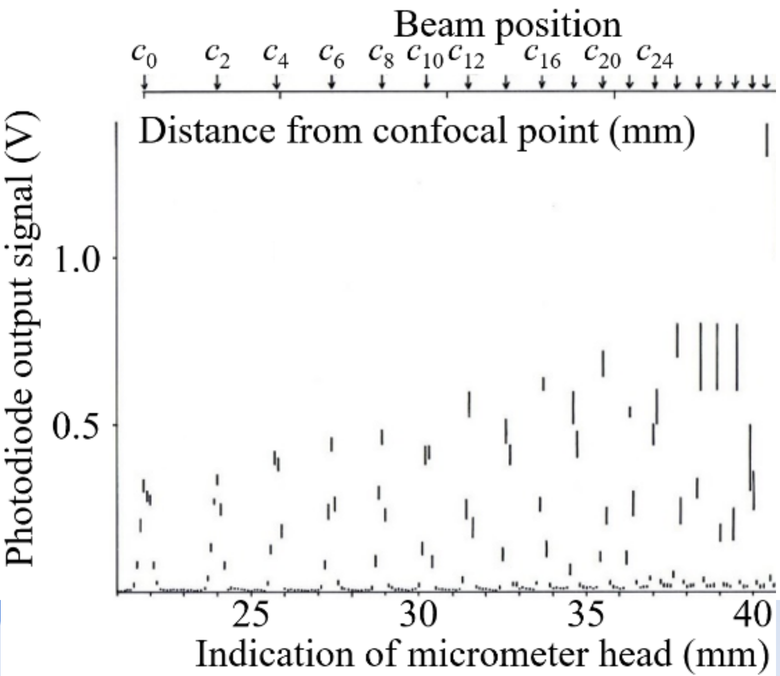

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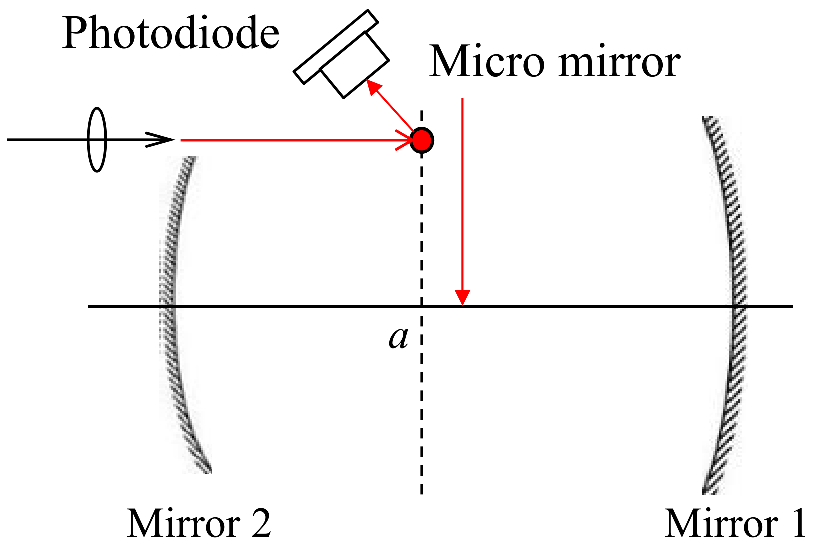

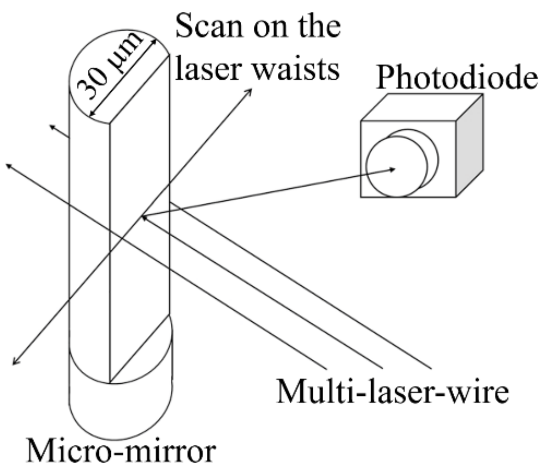

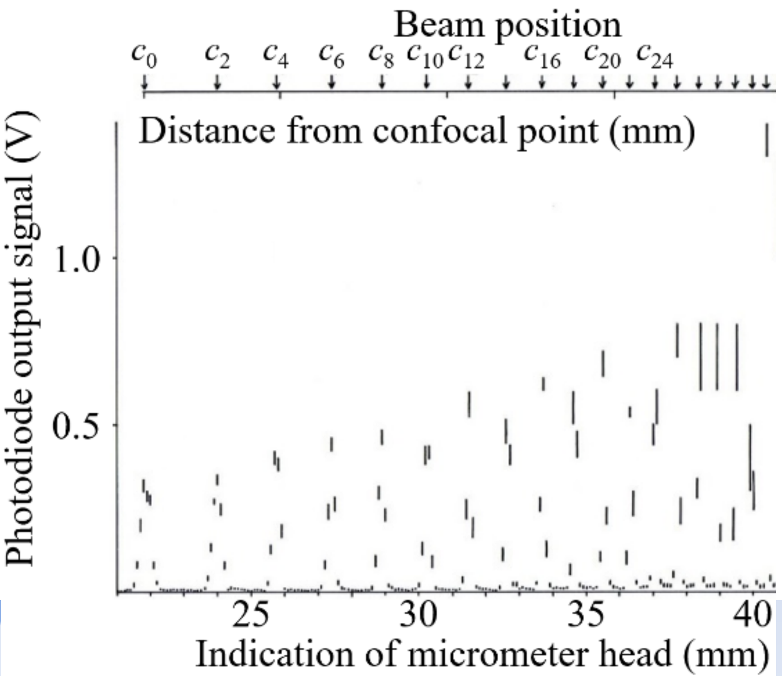

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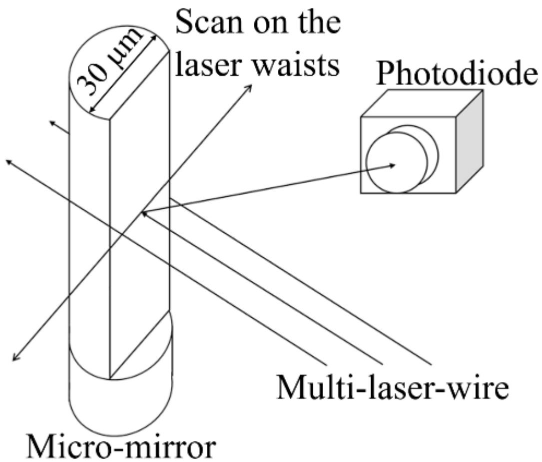

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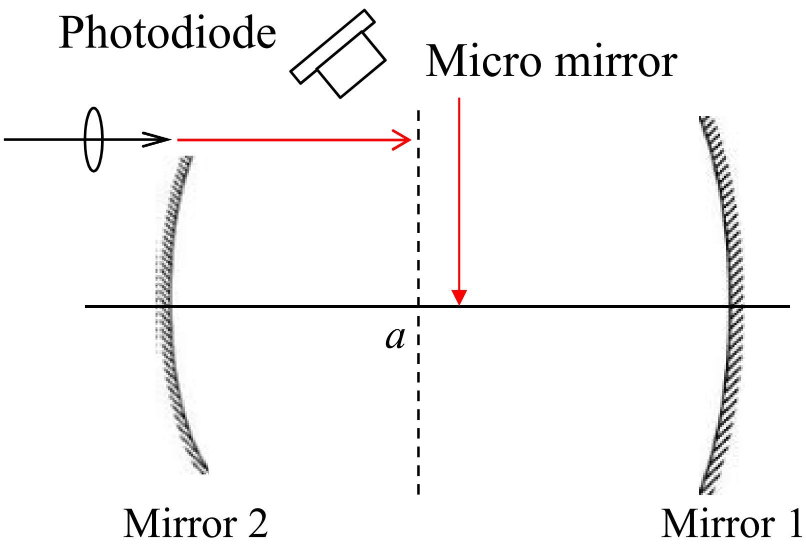

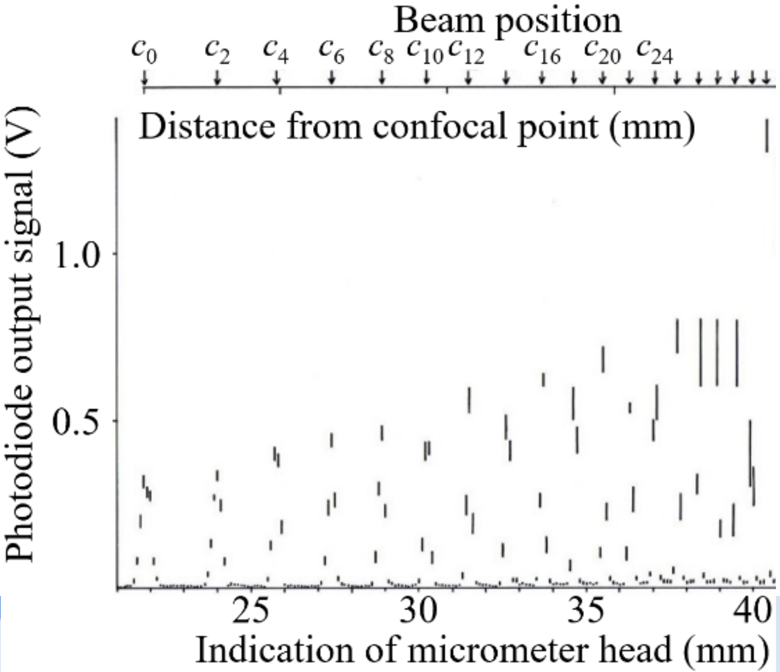

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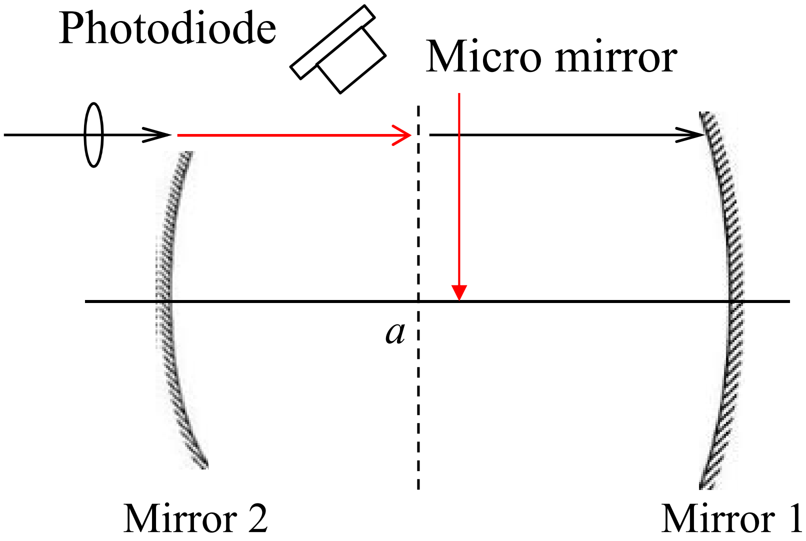

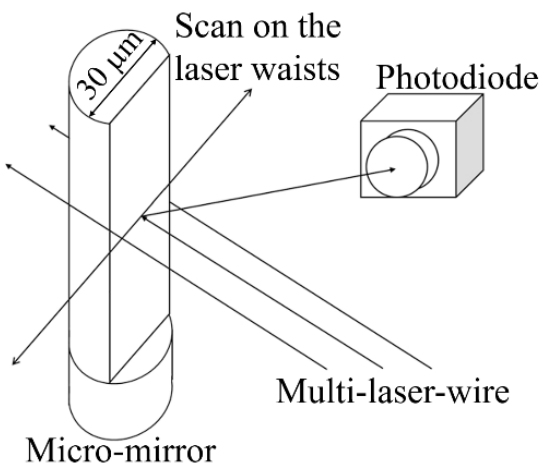

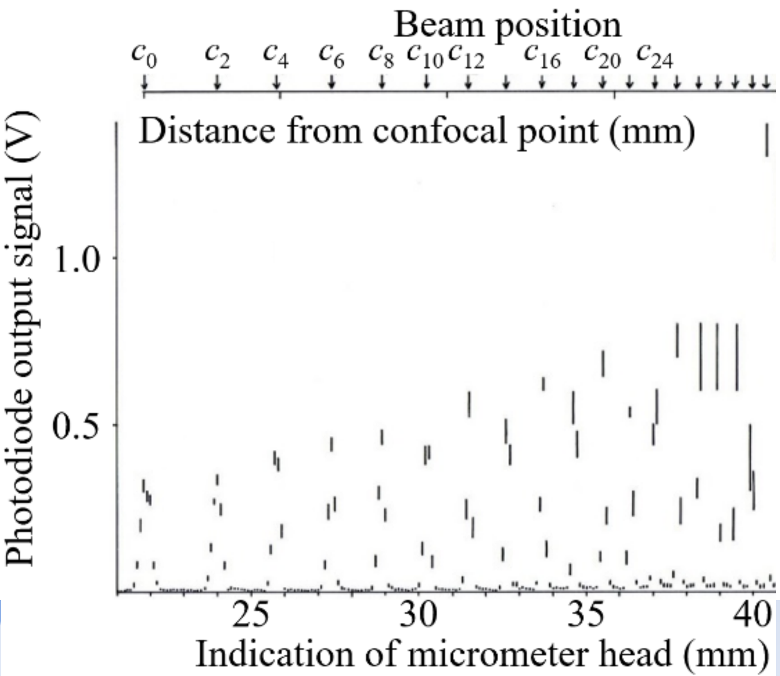

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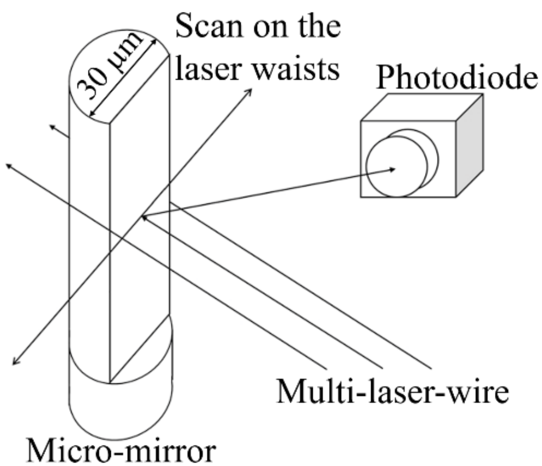

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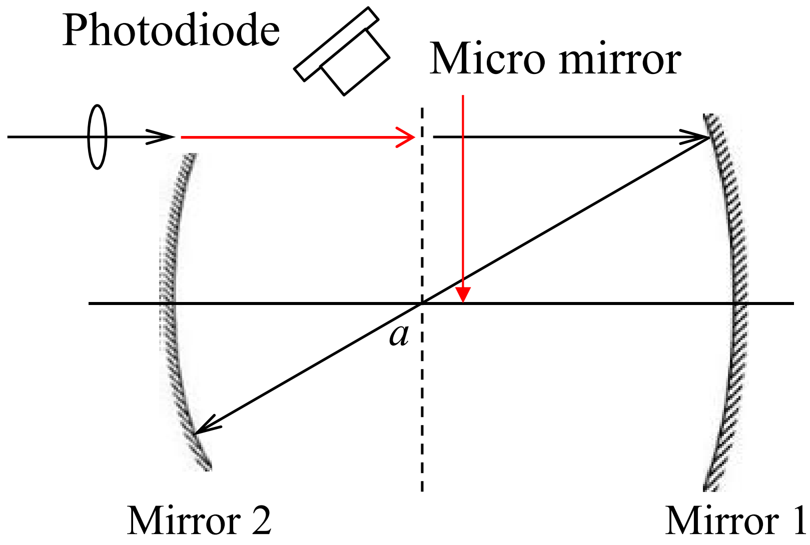

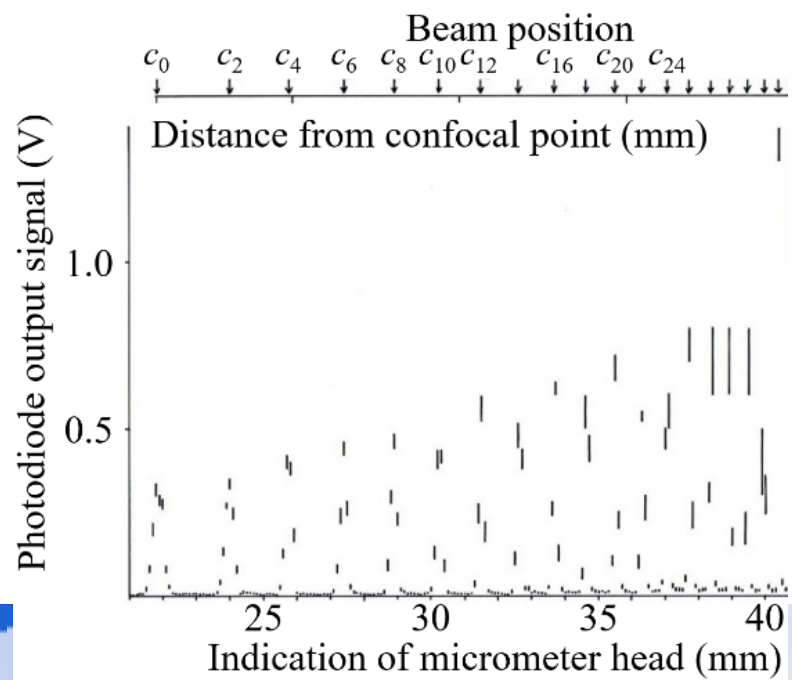

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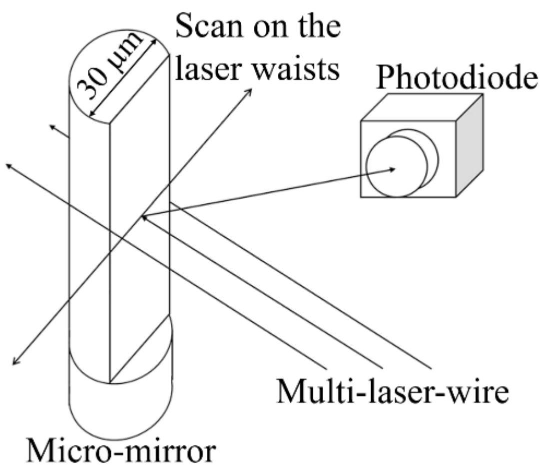

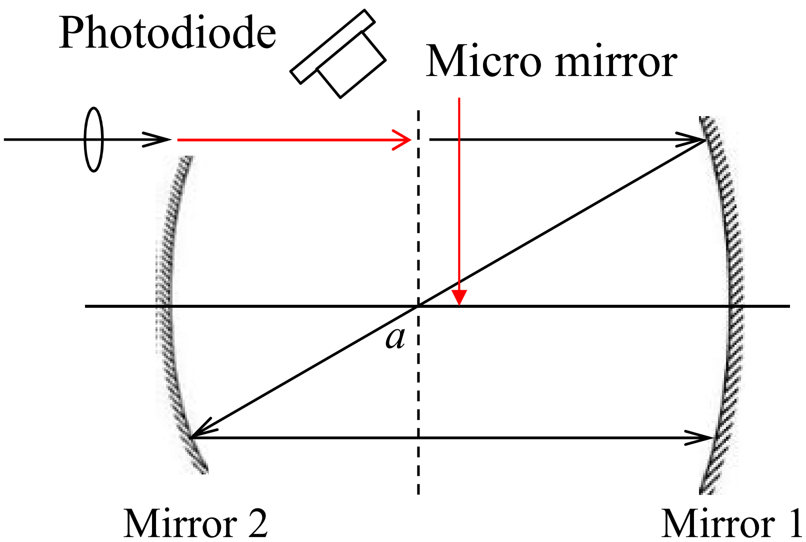

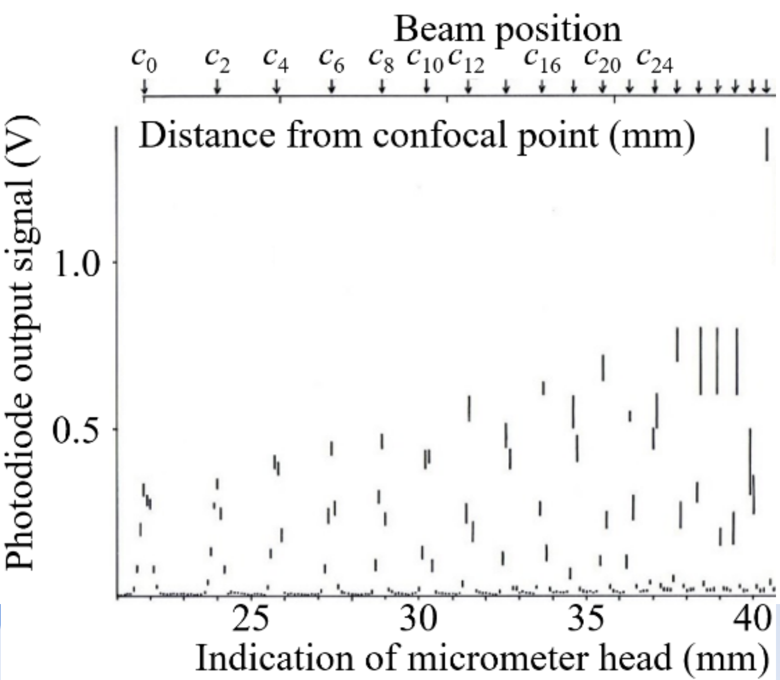

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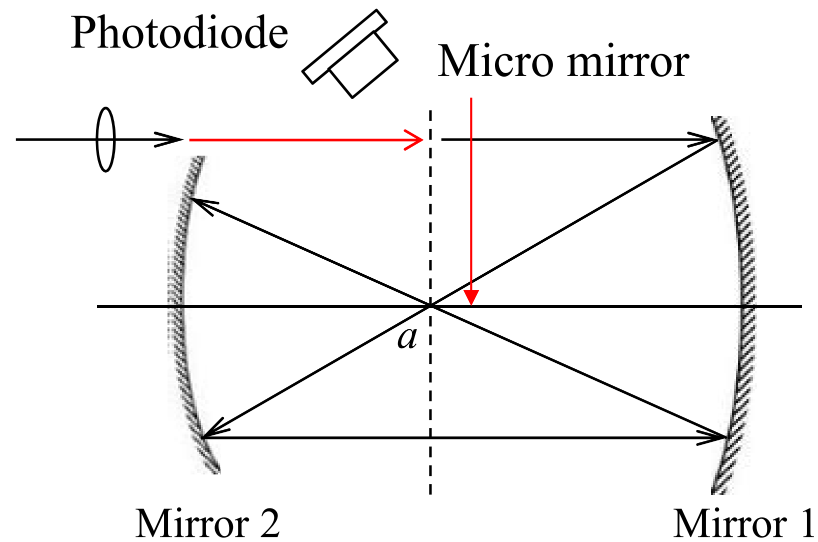

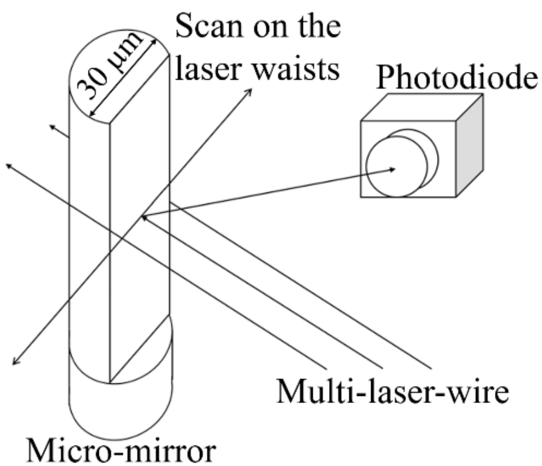

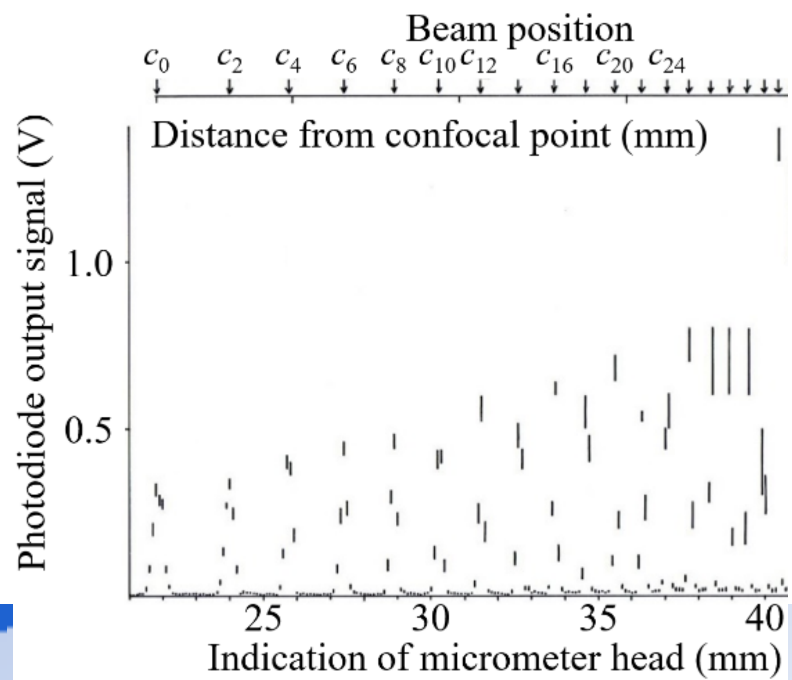

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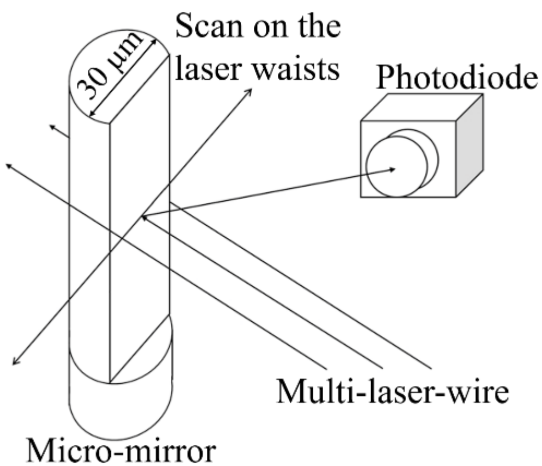

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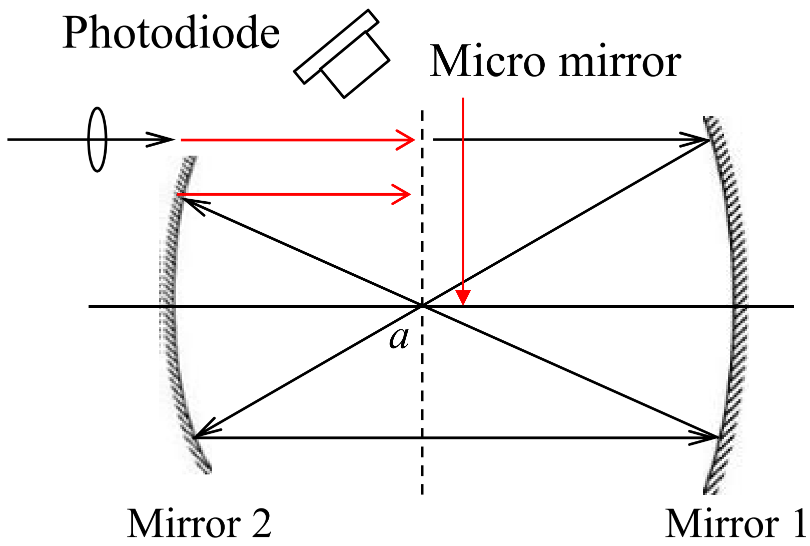

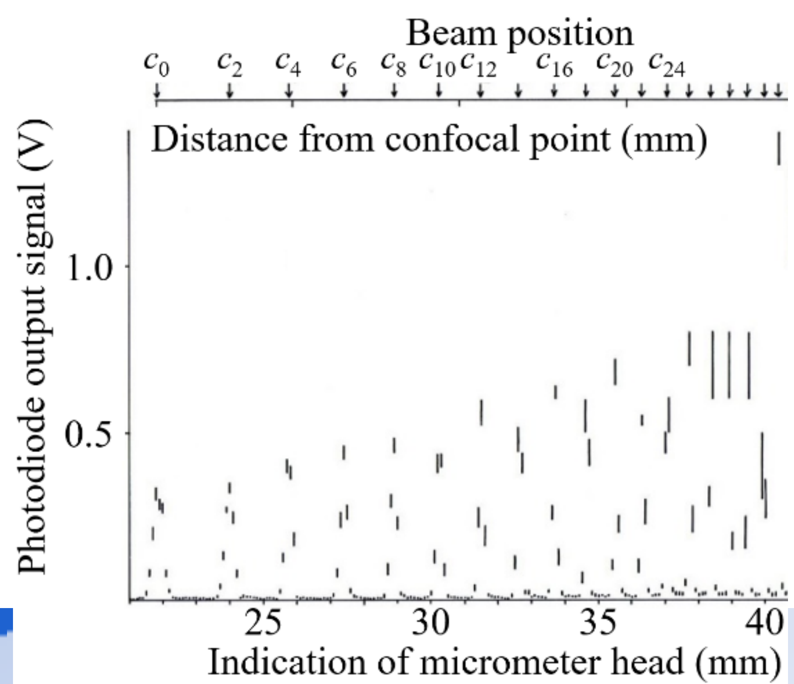

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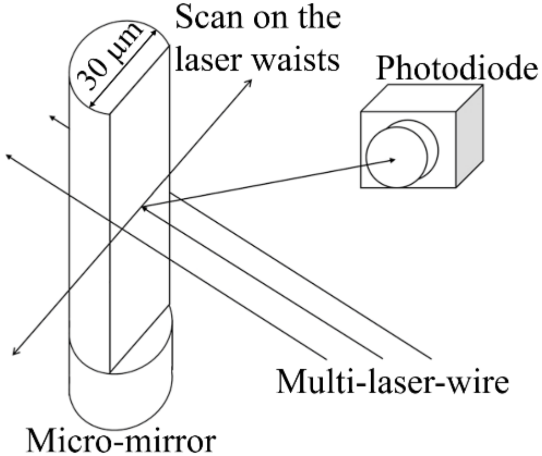

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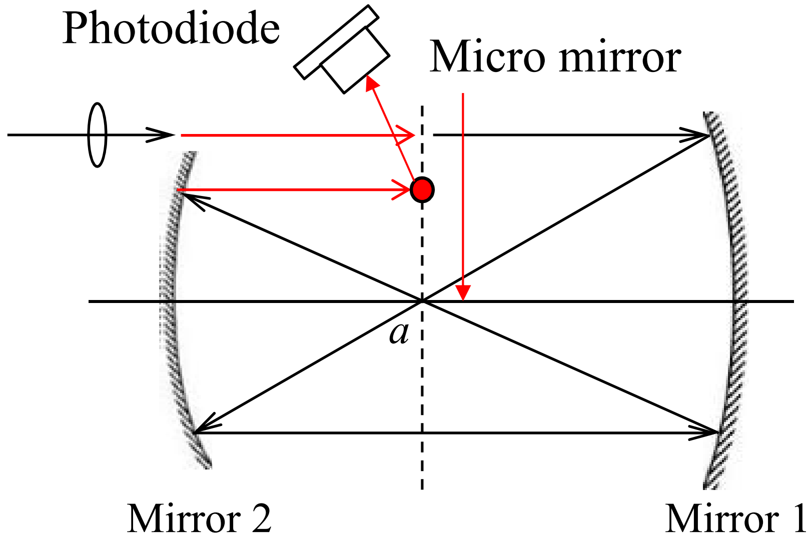

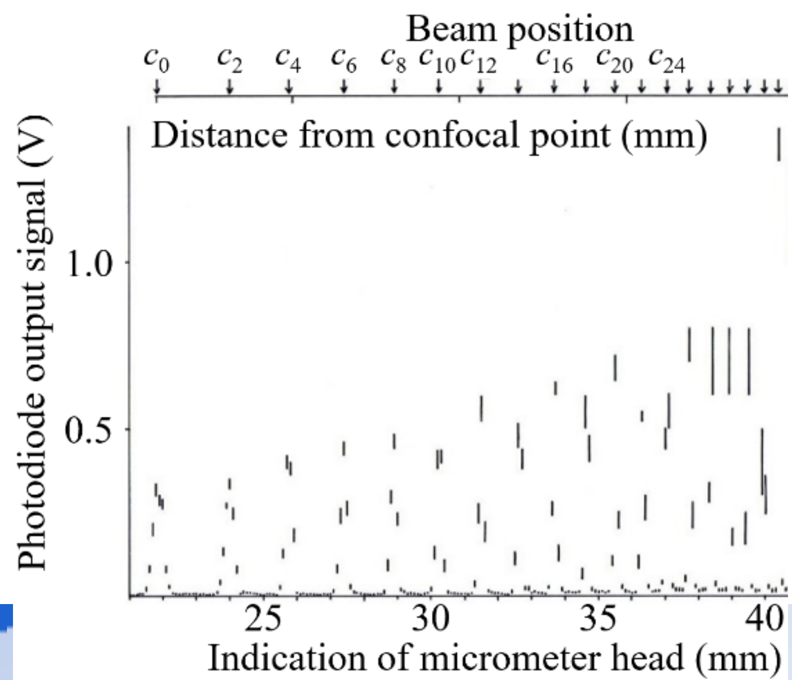

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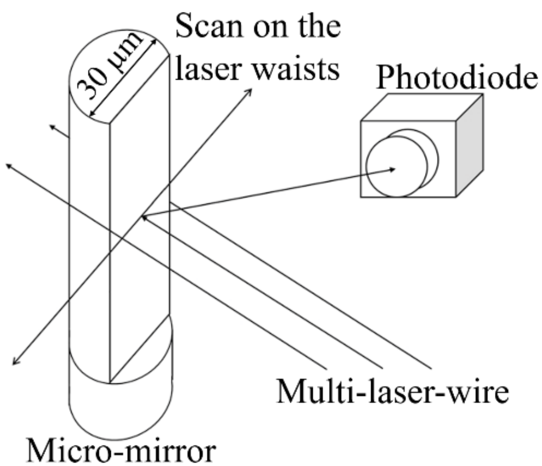

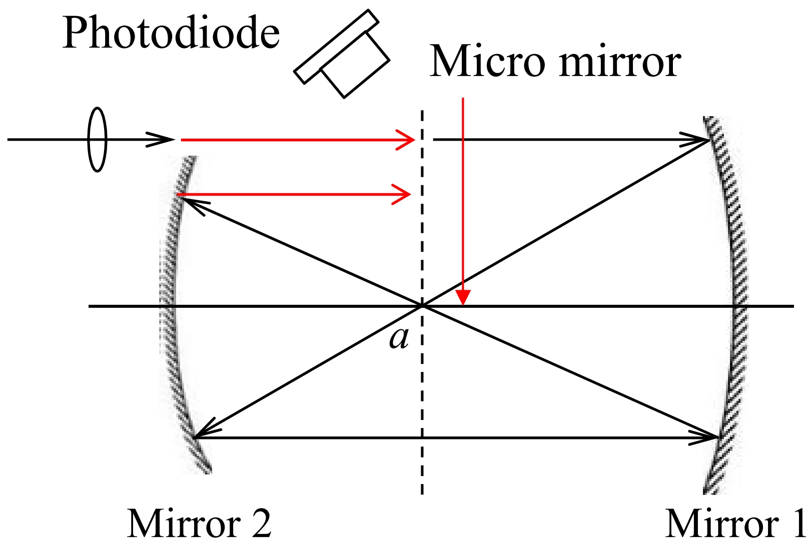

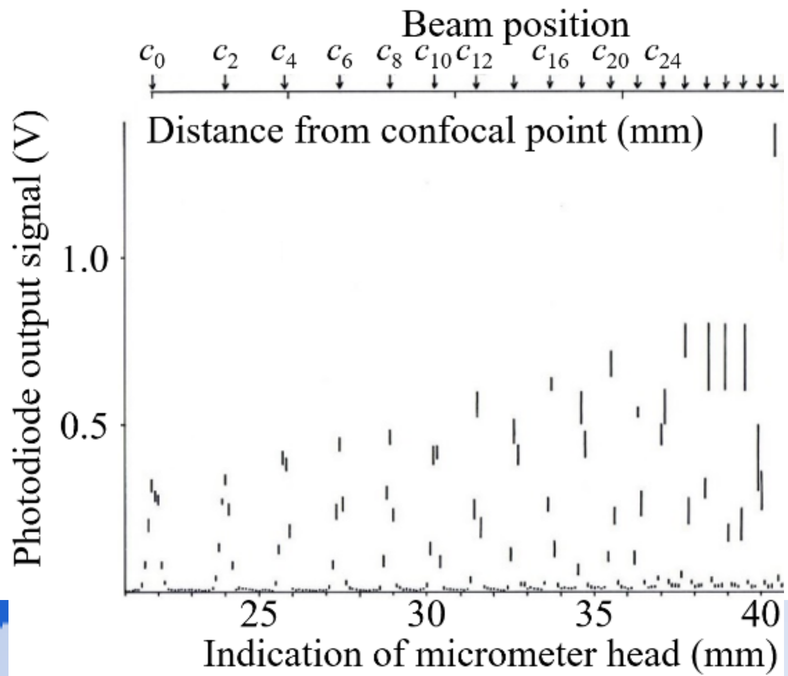

- We could count 24-laser spots at the top-half of the center axis clearly.
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4. Demonstration of the multi-laser-wire formation

laser intensity measurement using a micro-mirror

- A micro mirror is produced by ϕ30um gold-wire with optical flat surface.
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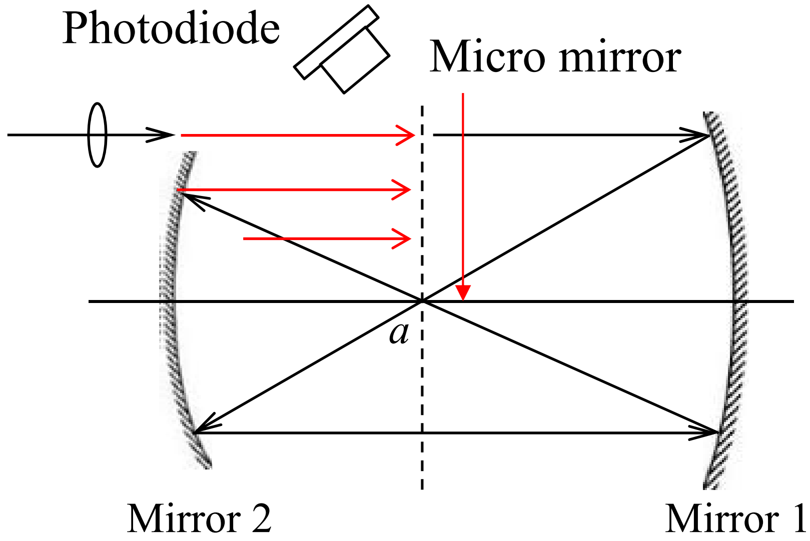

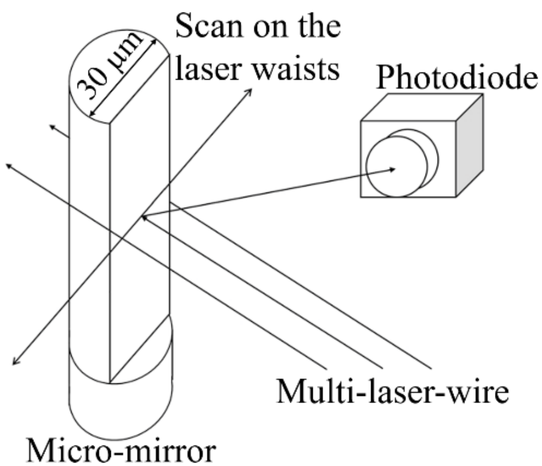

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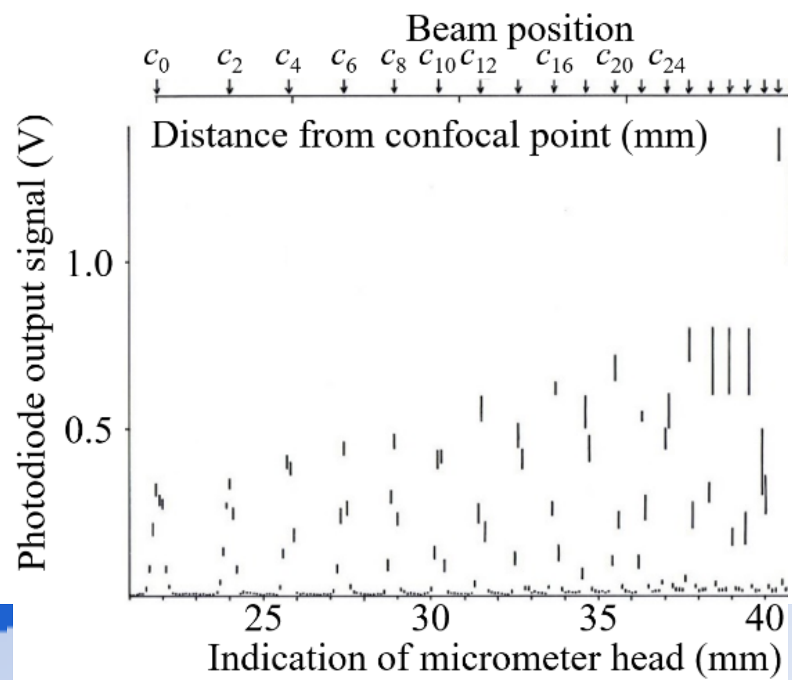

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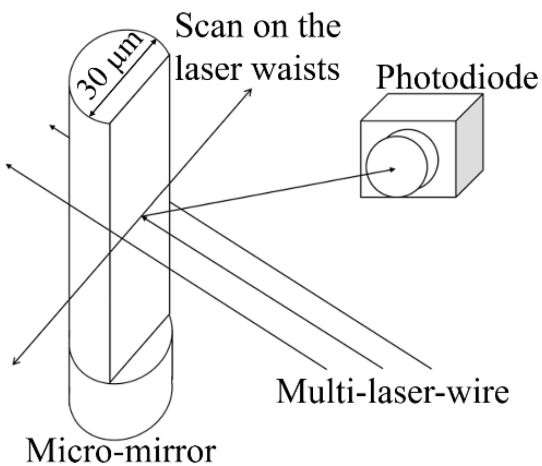

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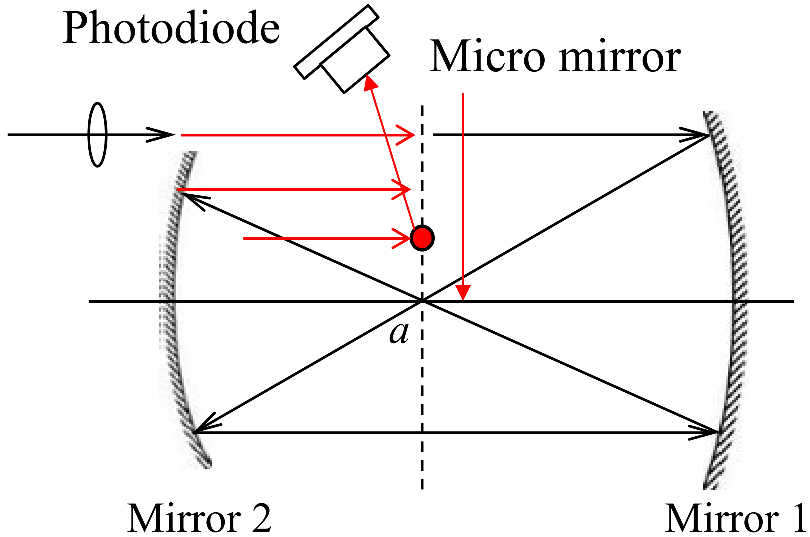

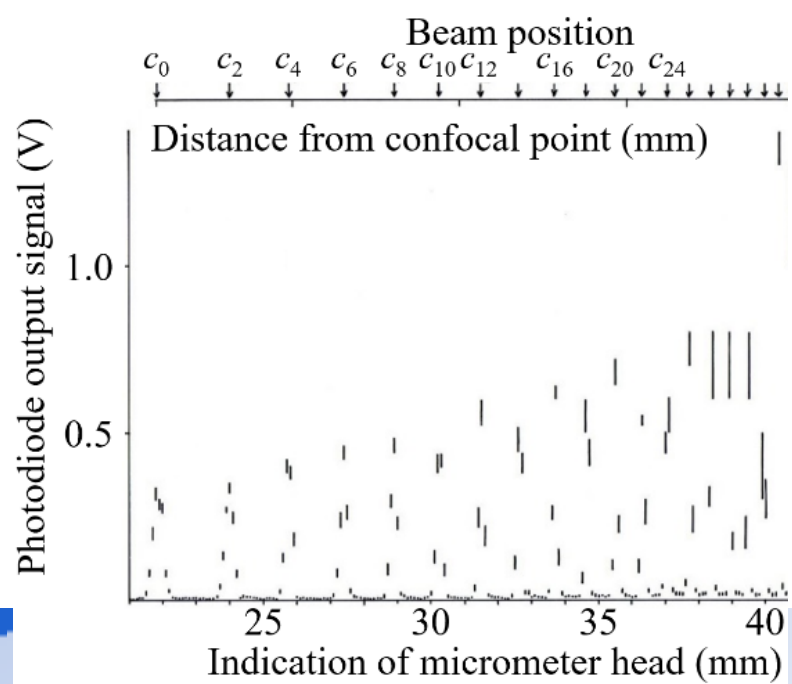

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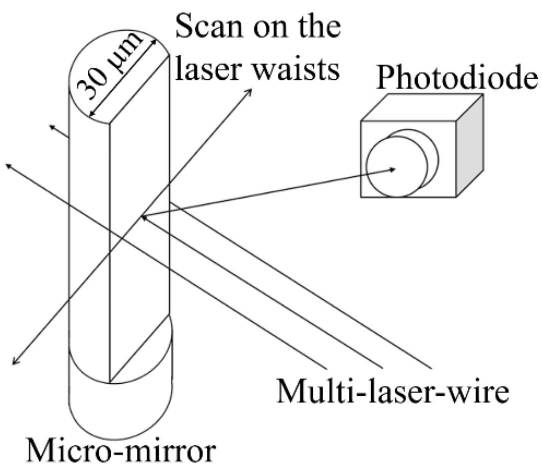

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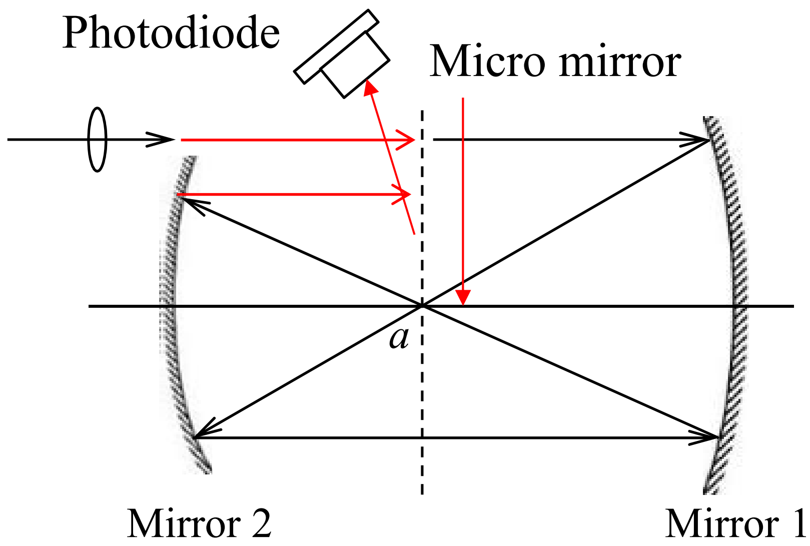

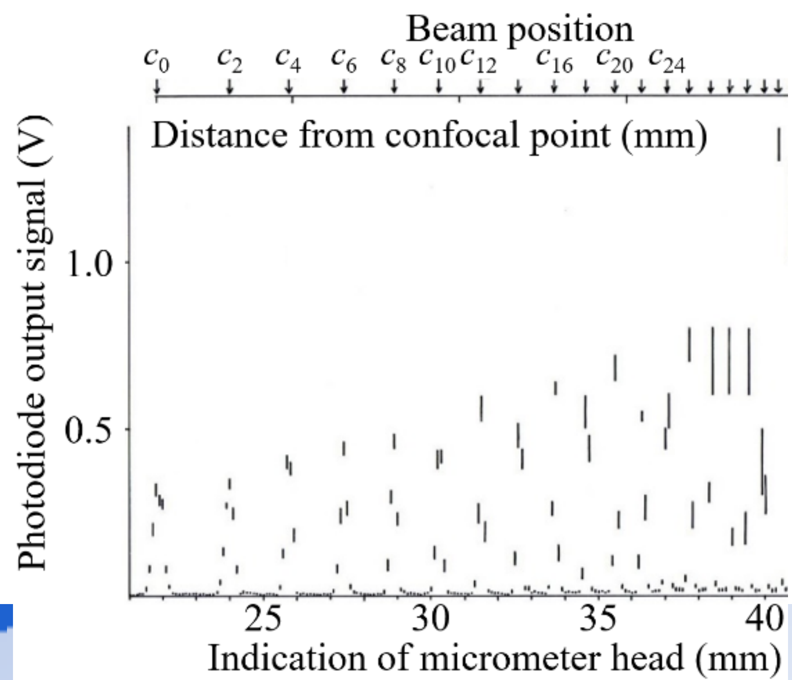

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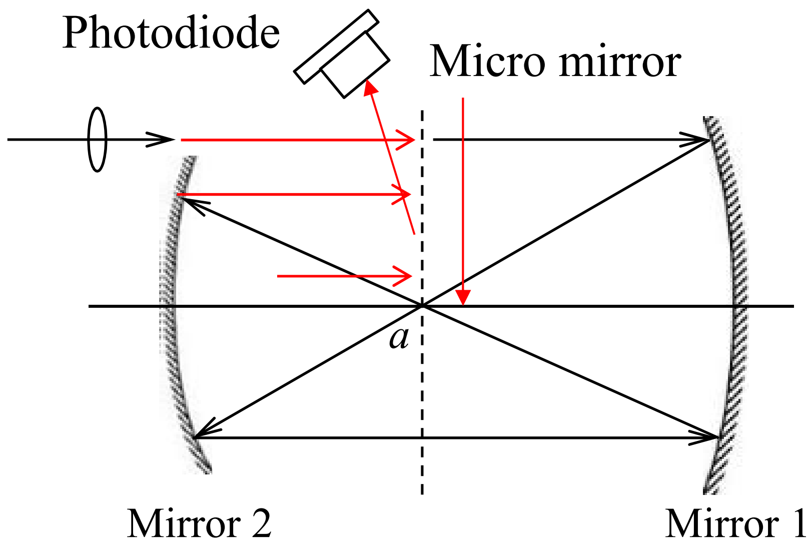

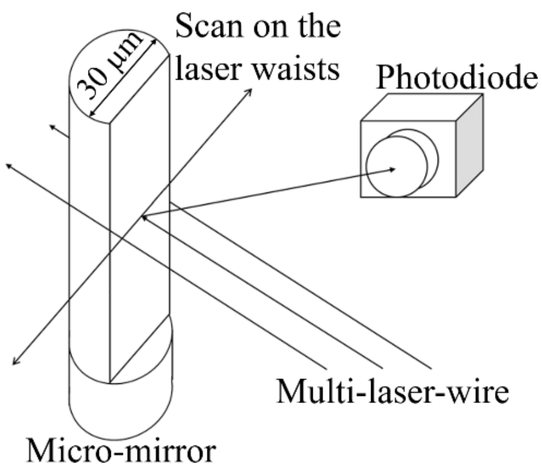

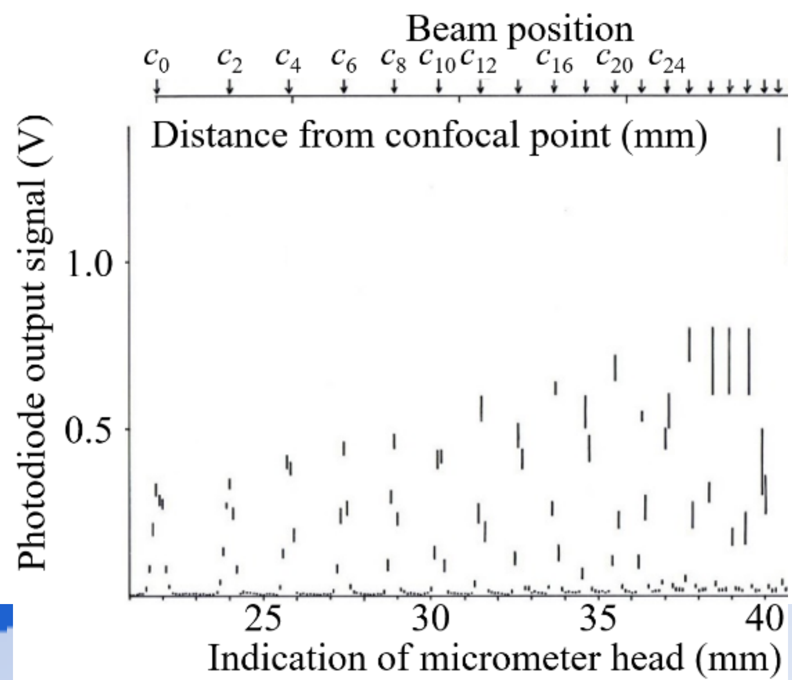

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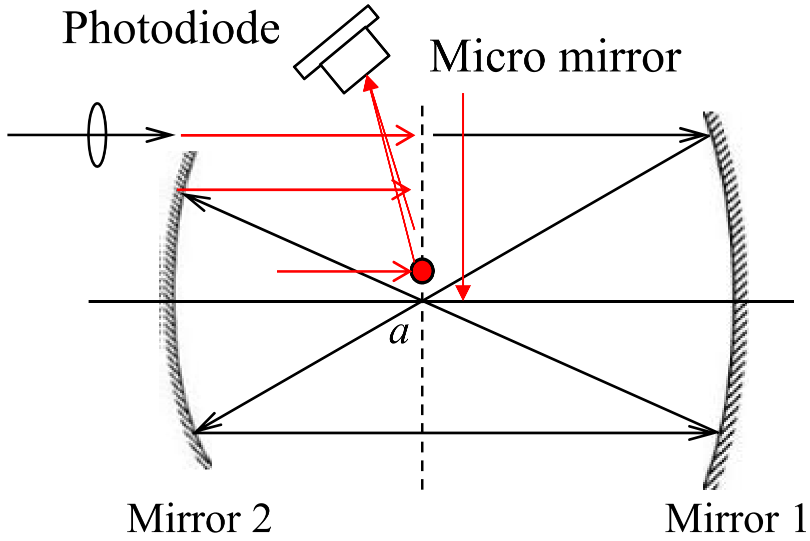

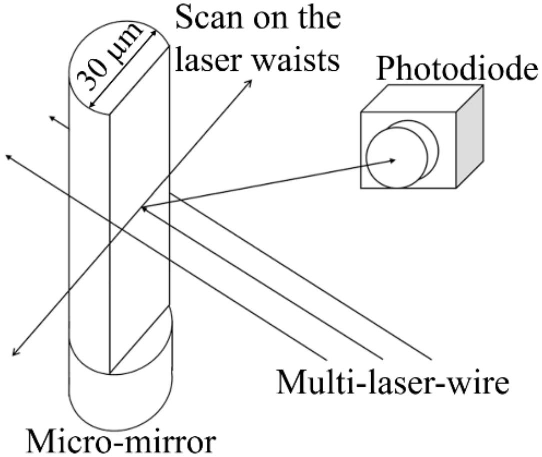

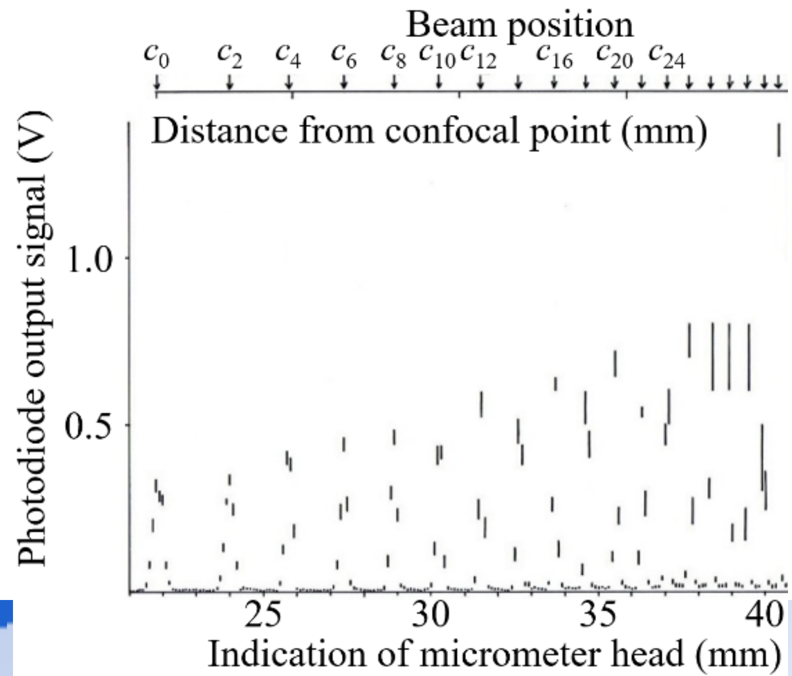

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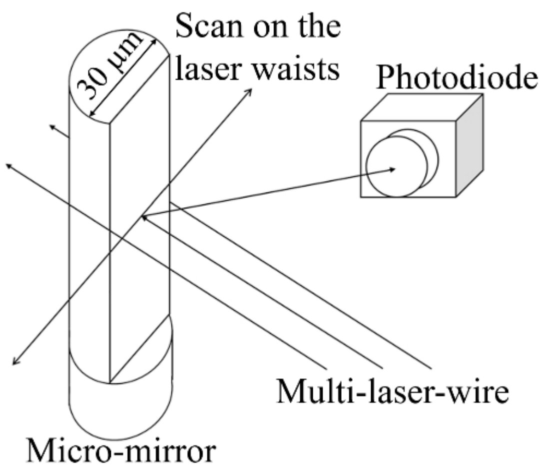

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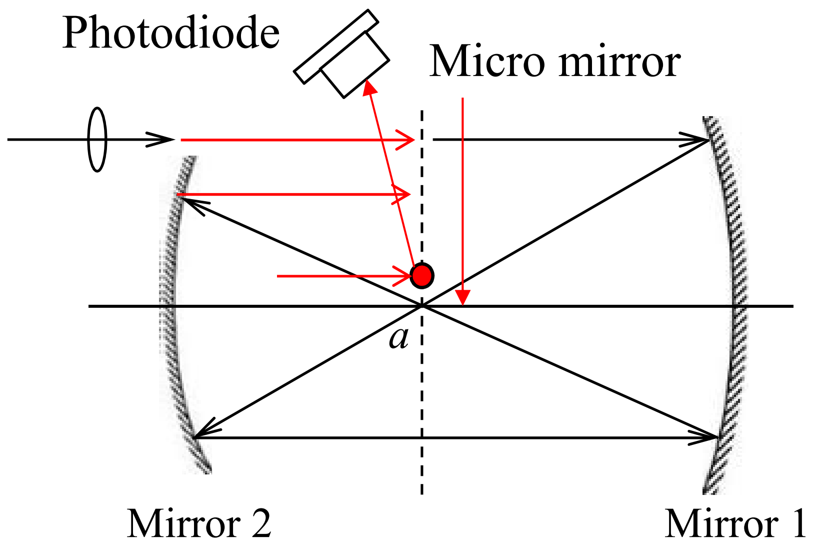
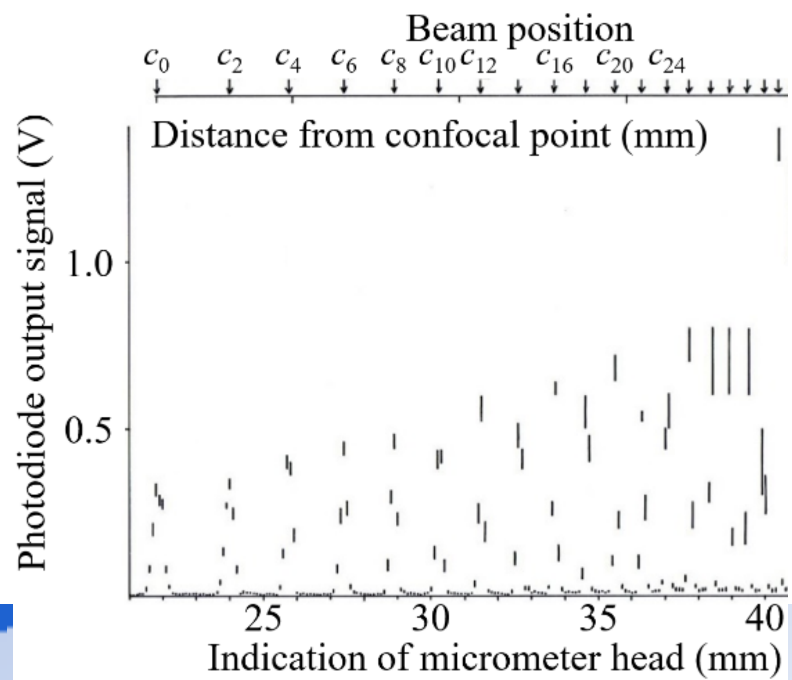
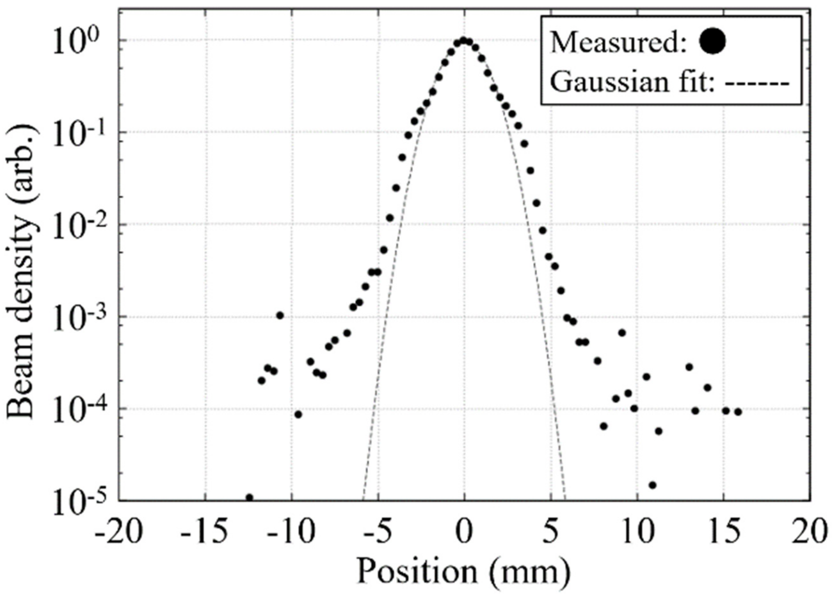




5. Design of the multi-laser-wire profile monitor

Horizontal resolution and dynamic range

- Minimum beam size is 2.0 RMS. Less than 0.2-mm intervals are required.
- The beam halo appears around 1/10 magnitude of the beam core. Over 10^2 dynamic range is required.

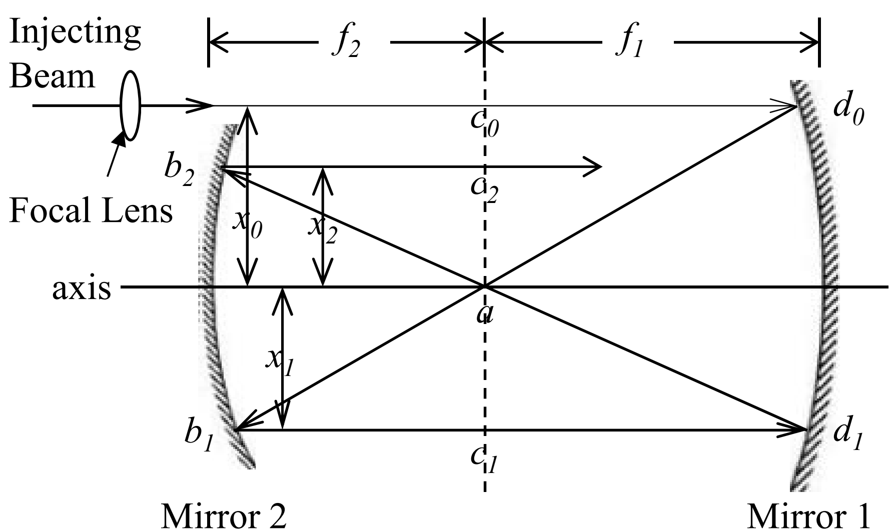


Transverse profile taken by WSM

Time intervals

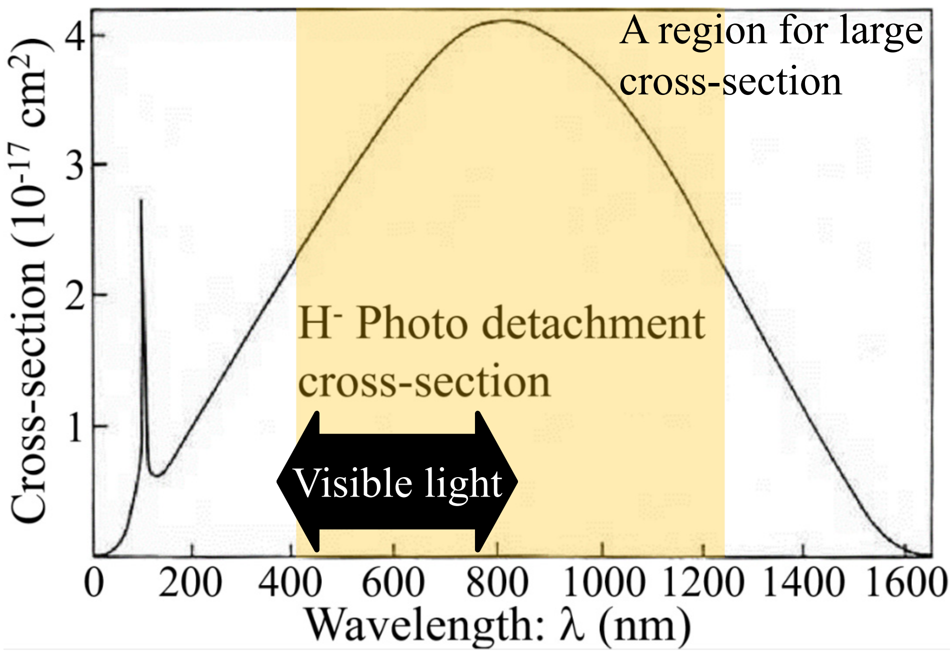
- Accelerated beam duration is 3.01 ns intervals due to 324 MHz RF.
- Time of the laser beam round trip is $4L/c$ ($L = f_1 + f_2$).
- Laser beam flight time should be in the RF repetition timing, i. e.,

$$\frac{4L}{c} = \frac{n}{324 \times 10^6}.$$



5. Design of the multi-laser-wire profile monitor

Wavelength of laser beam



- Wavelength should be matched the cross section of the photo detachment of H^- to H^0.
- Visible light (l = 380-800 nm) is included in the large cross sectional region.
- When we chose the longer or shorter wavelength, we can take a match to the largest cross section with incident angle described by following eq.

$$\lambda_{PRF} = \frac{\lambda_{LF}}{\gamma(1 + \beta cos\alpha)}$$

Requirements of the laser profile monitor	
Wavelength	400 – 1200 nm
Horizontal resolution	< 0.2 mm
Dynamic range	> 10^2
Measurement time	2.5 mins / profile

6. Conclusion

Advancement of the multi-laser profile monitor

- No scanning device is required.
- It is non-destructive to the accelerated beam.
- Fast data taking.

Summary

- Demonstration of the multi-laser-wire formation was conducted.
- We set the specification of the laser profile measurement.

Future works / Discussions

- Noise reduction due to electrons come from physical process.
- Need to decide the electron detector.
- Design, fabrication and test at 3-MeV beam line.
- Application to the 400-MeV beam line.