Space Lidar Activity in Toshiba

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1 Introduction

In these decades, large scale spaceborne optical sensors become very popular for spectrometer for atmospheric research as well as Earth observation imager and astrophysics. The LITE operation demonstrated that large lidar system can provide useful aerosol measurement data.

Though Interferometric Monitor for Greenhouse gases (IMG), which is a large aperture Fourier transform spectrometer shipped last year, is a first experience of such large optical sensor, many sun sensors, star sensors, CCD cameras and X-ray astronomical sensors have been provided. In these sensor the important techniques for space lidar were developed,

- Light weighted and highly accurate optical system.
- Spaceborne laser (HeNe) development.
- Large optical sensor system design and integration.

Moreover Toshiba has enough technology applicable to space lidar system such as,

- YAG laser system, mainly for manufactural usage.
- Large size high-precision machining capability up to 1000 mm class optics.

In this paper, the related techniques are briefly reviewed, then, we describe a small lidar system which will be provided for an asteroid sample-return mission and approach to a larger Mie lidar system.

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2 Heritage

The laser is a key device of lidar.

Manufacturing Engineering Research Center (MERC) is a development center for gas and solid laser. Figure 1 shows wide variety of the manufactural YAG lasers including LD and flush lamp pumped system. In 1990, Toshiba developed the largest power of 2.4 kW YAG laser [1] in the world at that time.

Toshiba supplied many solid lasers for scientific research program as well as manufactural field to national research institutes, e.g. "Automatic Laser Radar System for Measurement of Atmospheric Pollutants[2]".

On the other hand, Toshiba has been intensively investigated other solid laser technology, such as alexandrite laser and its nonlinear wavelength conversion[3], near infrared CTH:YAG [4] and Er:YAG laser.

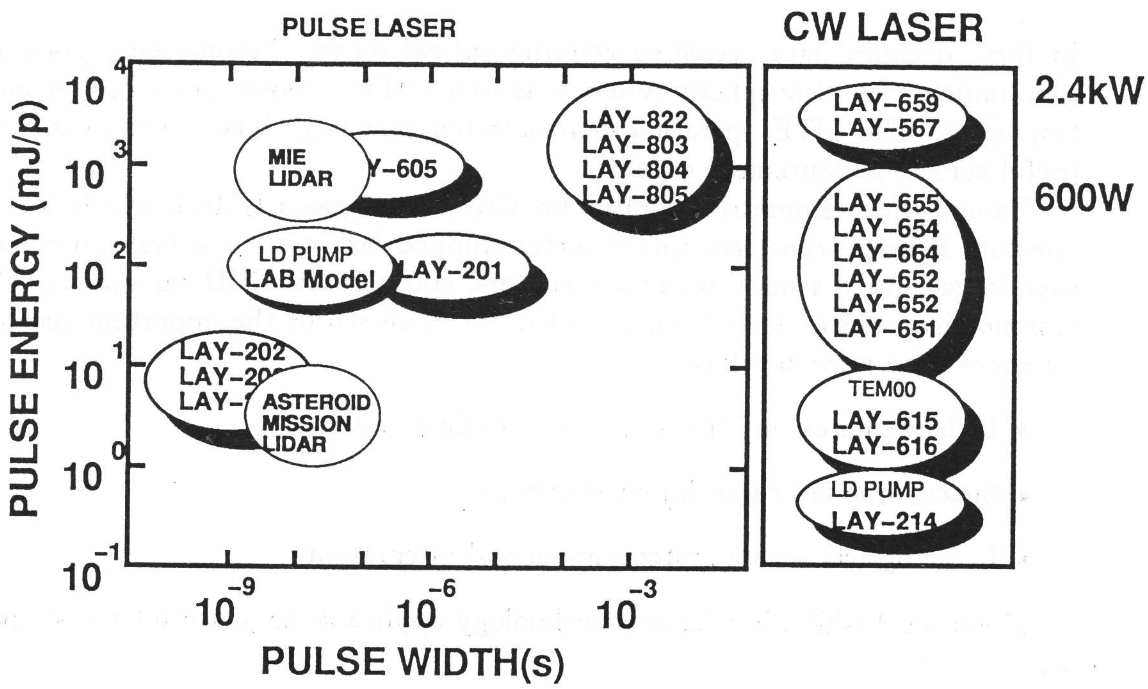

Figure 1: YAG-LASER heritage. The shadowed ellipses show the manufactural YAG LASER and others show space lidar requirements.

Toshiba can contribute on the field of large scale optics, other key component.

MERC has been intensively investigate ultrapresition parts manufacturing technique using computerized numerical control (CNC)[5][6].

Cutting, grinding and polishing are employed for various substrate such as glass, metal and glass ceramic to be obtained the form accuracy and surface roughness of order of 0.1 μm and nanometer respectively. The technique has been contributed many field, large scale copper mirror for giant pulse laser fusion research, X-ray and extreme ultraviolet reflective optics for plasma diagnostic and astronomy, Zerodur optics with 30 cm aperture for space laser communication study, highly accurate aluminum mirror ($\sim 1/10\lambda$) for space Fourier spectrometer IMG[7], and so on.

Recently, large machine with 1 meter working bed was developed for lager objects machining[8].

3 Lidar for Asteroid Sample-Return Mission

Toshiba started the study of a lidar for asteroid sample return mission. The lidar is very compact will measure the range to asteroid Nereus on approach within 50 km.

Toshiba will develop its 5 mJ diode pumped Nd:YAG and light weighted Cassegrain optics in house. The design goal of the lidar is shown in Table1.

In order to satisfy the requirement, laser resonator optical layout should be designed with light weighted holding to survive in the launch environment of M-V launch viecle. The ultra-lightweighted primary optics with 210 mm aperture will be archived by Silicon Carbide (SiC). The SiC has grate advantage in high stiffness and high thermal stability than glass and metallic mirrors. The weight of mirror will be comparable to beryllium.

The develop schedule is shown in Figure 2. The BBM laser is just integrated. The SiC mirror tooling condition has been evaluated by sample piece. The BBM fabrication is the next step.

Table 1: Design goal of asteroid mission lidar

Total Mass	2kg.
Total Power	5 W
Usable range	50m to 50km
Range accuracy	10
Pulse Energy	5 mJ
Pulse Rage	1 pps
Pulse Width	20 ns
Optical Apertur	210 mm

4 Larger Lidar Approach for Atmospheric Research

The Mie scattering lidar require 1J class laser (see Figure 1). Toshiba has developed a laboratory model diode pumped 100 mJ YAG laser and study the thermal effects on its power, mode, etc. Attach the amplifier module will make the larger power basically. The heat extraction of a few hundreds Watts with heat spot of LD and YAG module will be a major problem for space application.

The space lidar will require larger aperture about 1m. Glass mirror will be too heavy for our space application. Though beryllium mirror may be light enough, its oxide has toxicity that the machining has difficulty and expensive in Japan. Toshiba has an idea to apply the SiC technology developed for ranging lidar optics. The SiC high thermal stability and stiffness will be effective in larger structure, since minimum thickness of SiC limits the weight for small size mirror. The weight of 1mϕ mirror

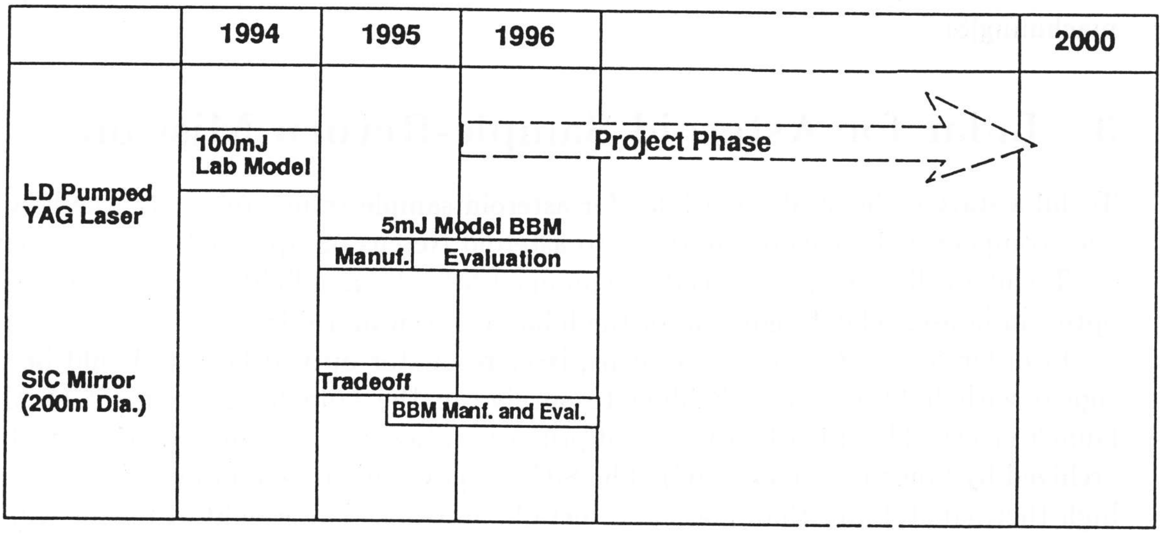

Figure 2: Lidar key technique development schedule for Asteroid Sample Return Mission

based on current design of small lidar is roughly estimated 25 to 75 kg. Further investigation will reduce its weight.

On the basis of these key technology and system engineering capability of space program, Toshiba has a capability to develop most of the Mie space lidar system in house and optimize the system to fit the space flight requirement.

References

[1] S. Yoshida, et el. ; *CLEO '90 Technical Digest* CTUJ4, p.118, 1990.

[2] H. Kimura, et al. ; *Trans. IECE '81/7* Vol. J64-C, No7, 1981.

[3] S. Imai, et al. ; *Appl. Phys. Letter* **54**, p1206, 1990.

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[5] K. Ueda, et al. ; *Annals of the CIRP* **40**, p555, 1991.

[6] K. Ueda, et al. ; *Thoshiba Review* **48**, p479, 1993.

[7] K. Tsuno, et al. ; *SPIE* **1490**, p222, 1991.

[8] K. Amano, et al. ; *Proceedings on the meeting of the Japan Soc. of Precision Eng. 1995* p913, 1995.

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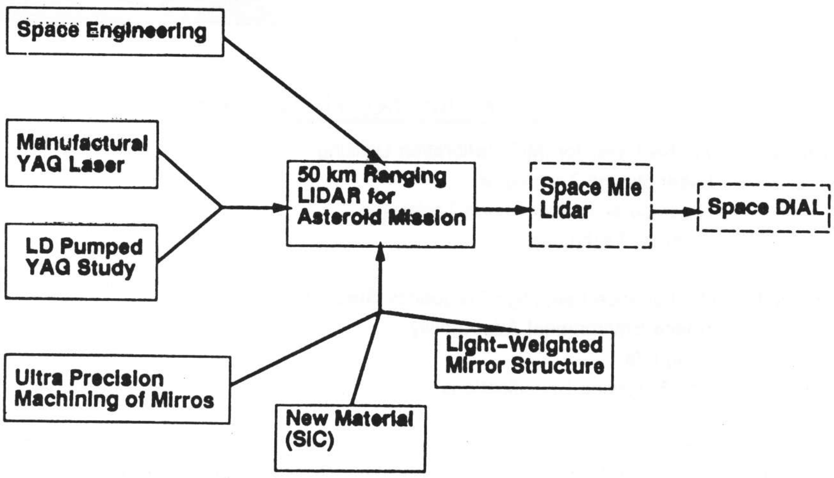
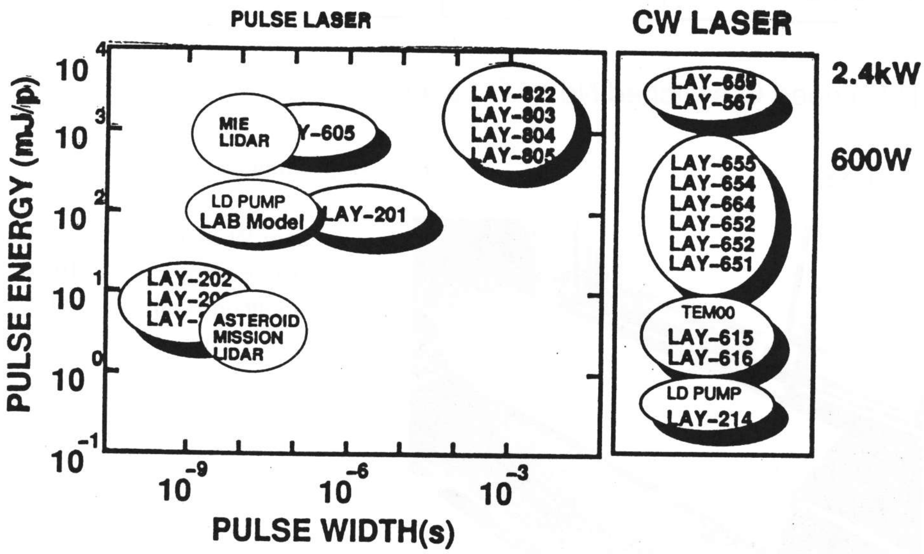
International Workshop on Spaceborne Lidar 1995

24–26 Oct. 1995, NARA

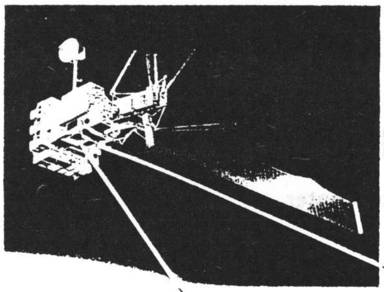
Space Lidar Activities and Contributions



YAG Laser Heritage

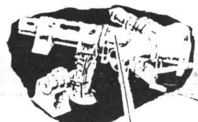


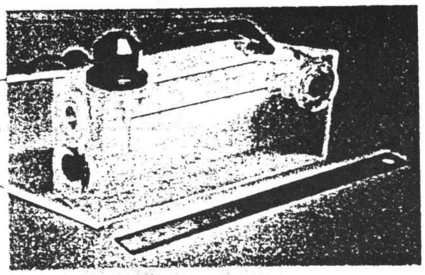
Spaceborne He-Ne Laser



ADEOS:Advanced Earth Observation Satelite
Launch Scheduled for August 1996

He-Ne Laser
Calibration for Absolute Standard Wavelength





MG:Interferometric Monitor for Greenhouse Gases
Monitor CO2,O3,N2O and Other Greenhouse Gases

Michelson-type Fourier Transform Spectrometer

Space Qualified He-Ne Laser

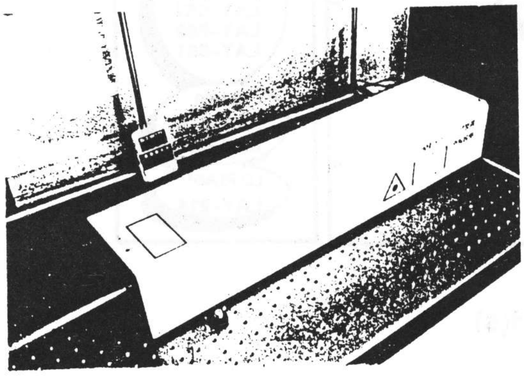
· Developed He-Ne Laser for IMG Calibration Utilizing
Laser Design Technique
Glass-ceramic Processing Technique
Vacuum Technique

· Achieved Maintenance-free, High Frequency Stability
Space Environment Adaptability
Long Life
The Following Specifications :

Wavelength	633nm	Power Consumption	1.9W
Frequency Stability	$\pm 1 \times 10^{-7}$	Mass	0.78kg
Certainty	± 50MHz	Volume	$49 \times 92 \times 145 mm^3$
Mode	TEM_{00}		
	Single frequency	Reliability	0.934
Laser Beam Power	0.5mW	Operation term	3years (duty0.46)
Polarization	Linear($>10^4$:1)	Estimated life	2×10^5 hours

LD Pumped Q-switched Nd:YAG Laser

· Laser Head



· Performance

Laser Wavelength : 1064 nm
Pulse Energy : 100 mj
Repetition Rate : 100 Hz
Pulse Width : 25 ns

Advantage of Laser Design

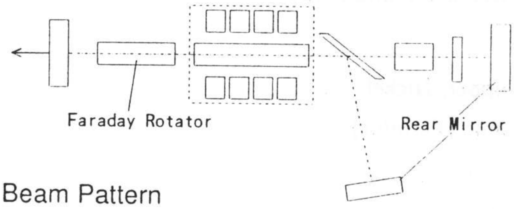
・Compensation Technique of Thermal Effects in YAG Rod

↓

High Efficiency

(example)

・Birefrengence Compensation Resonator

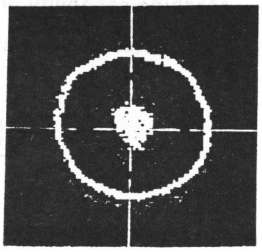


Compensation by Rotating Beam Polarization by 90 Degree

・Laser Beam Pattern

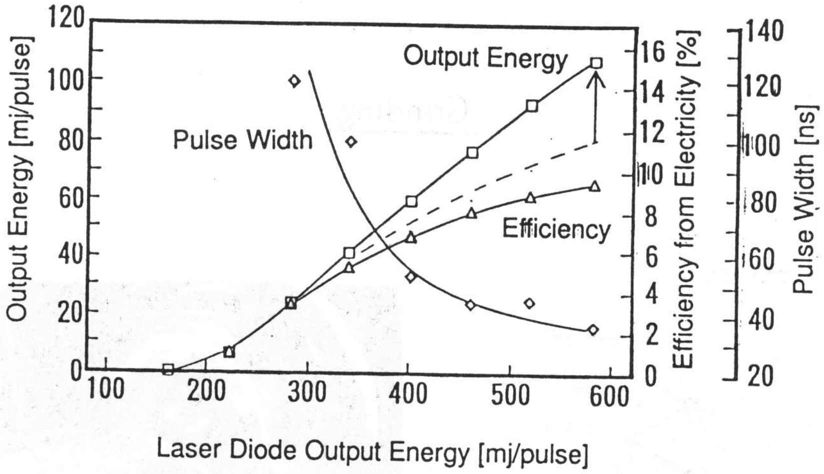
Compensation

→



100Hz Performance with Birefrengence Compensation

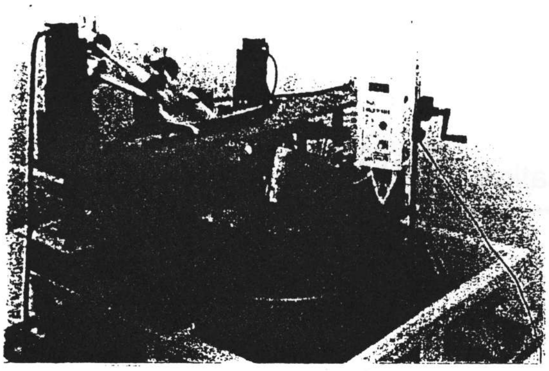
MANUFACTURING ENGINEERING RESEARCH CENTER

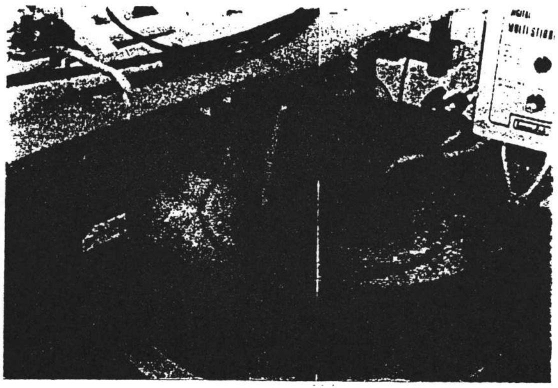


Mirror Manufacturing

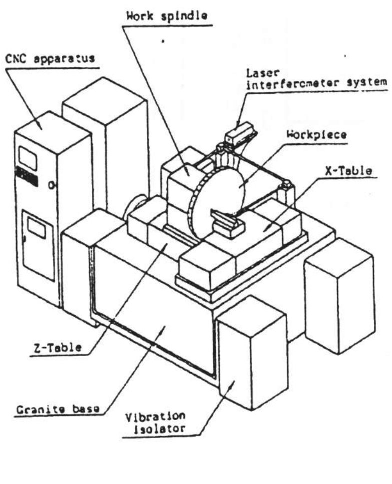
- Ultra Precision CNC Machining
  - Cutting, grinding and polishing
  - Form accuracy of an order of 0.1 micro meter
  - Surface roughness of an order of 0.1 nano meter
  - Visible, Infrared, Extreme UV and X-ray
- Material
  - Metal (Alminum, Cupper, Nickel, ...)
  - Glass and glass ceramic (Zerodur)
- Size
  - Machine capability of 1 meter diameter
  - 0.65 meter mirror was Completed

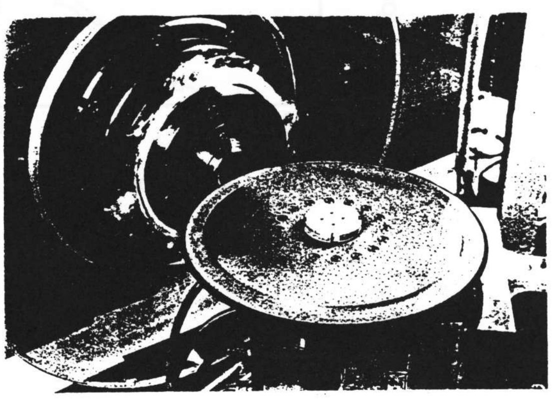
Polishing



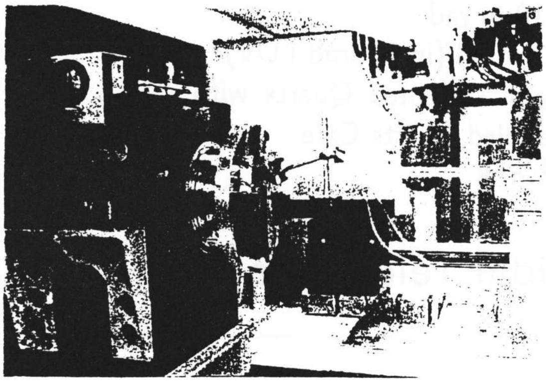


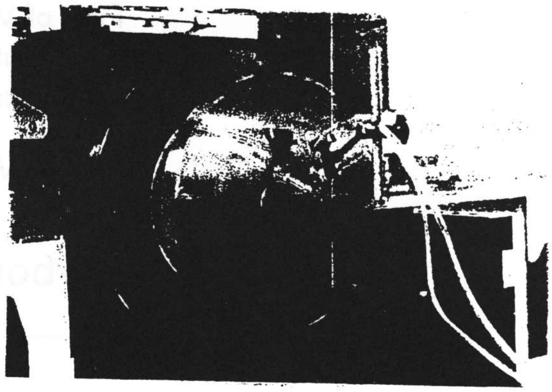
Grinding





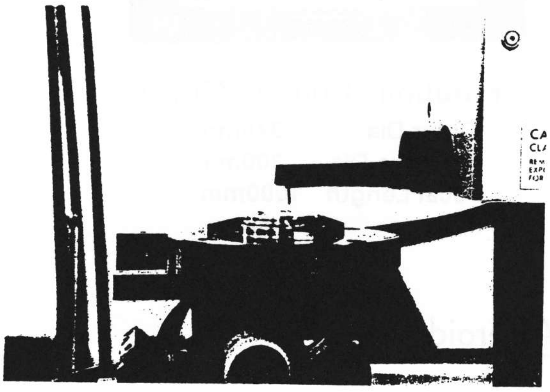
Cutting (Diamond Turning)



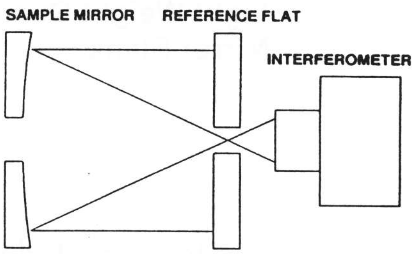


On Tool Measurement

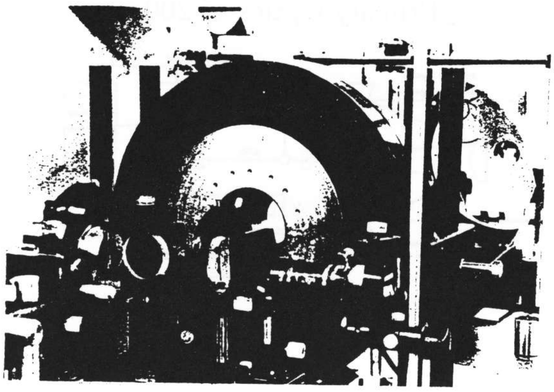
Probe Measurement

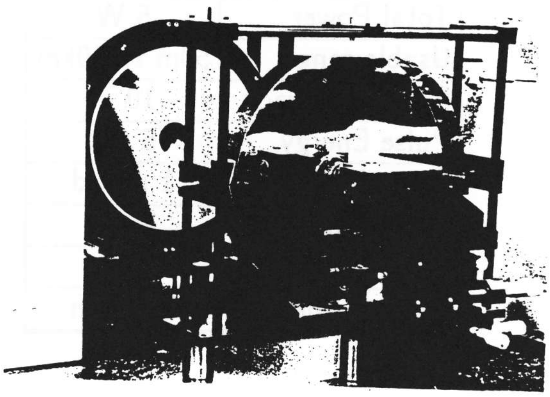


Inteferometer Measurement



Telescope Integration

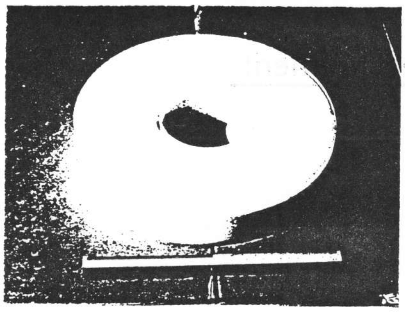




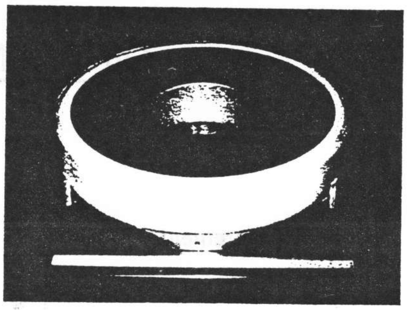
<u>Airborne Lidar Telescope</u>

Telescope Type:	Folded Parabolic Collector
Focal Length:	1000 mm
Effective Aperture:	300 mm
Field of View:	$\geq$10 m rad
Resolution:	0.1 mrad (in 2 mrad FOV)
Primary Mirror Substrate:	Light Weighted Quarts with Babbled Quarts Core
Mass:	14.5 kg

NASDA 宇宙開発事業団 Airborne Lidar Telescope



Light Weight Quartz Mirror Blank



Parabolic Primary Mirror

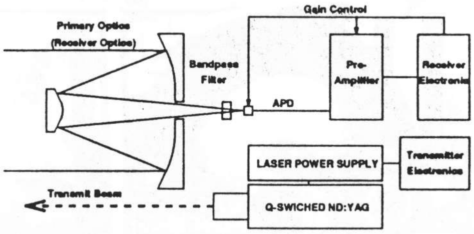
Outer Dia	340mm
Effective Dia	300mm
Focal Length	1000mm
Mass	3.8kg

Ranging Lidar for Asteroid Mission

- Range measurement on landing phase to asteroid
- Design goal

Total Mass	2kg.
Total Power	5 W
Usable range	50m to 50km
Range accuracy	10 m
Pulse Energy	5 mJ
Beam Width	1 m rad
Pulse Rage	1 pps
Pulse Width	20 ns
Optical Aperture	210 mm

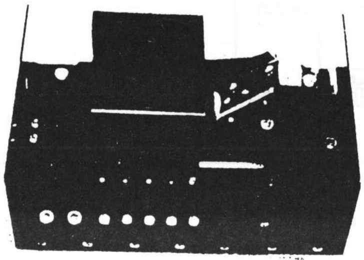
- Light weight component (Budget)
  - Laser Head of 250g
  - Power Supply of 400g
  - Primary Optics of 200g



Laser Design

- Key Considerations
  - Self-Compensated Resonator → Environment Adaptability
  - LD Side Pump → Power Flexibility
  - Conductive Cooling → Reliability
  - A Few Parts → Reliability, Light Mass

- Bread Board Model



SiC Mirror (Material)

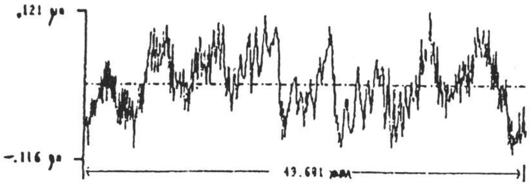
Material Trade Off (from D. Wang, et al., SSG Inc)

	ULE	Beryllium	Aluminum	Silicon Carbide Reaction Bonded	Silicon Carbide HP & Pressure Cast
Young's Modulus of Elasticity, E (psi) x 10^6	9.8	44.0	10.6	52.8	62
Poisson's Ratio	0.18	0.07	0.33	0.14	0.2
Coefficient of Thermal Expansion, α/°C x 10^{-6}	0 ± 0.03	11.2	23.2	2.1	2.0
CTE Variation, ppb/°C	10	100	100	50	< 50
Thermal Conductivity, K (BTU/hr ft°F)	0.76	87 - 112	109	99	105
Density, ρ (lb./in.^{3})	0.0795	0.067	0.100	0.106	0.115
Mechanical Figure of Merit (E/ρ) x 10^6	123	656	106	498	539
Thermal Figure of Merit K/α	25.3	7.7 - 10	4.7	47.0	52
Diffusivity D (in^2/hr)	4.3	39	320	*	460
Specific Heat Cp (BTU/lb°F)	0.0183	0.048	0.024	*	0.035
Stress Level (K psi) - Microyield - Ultimate	--- 2	5 - 24 > 15	12 45	--- > 15	--- 60 - 100

* Data not available, similar to CVD

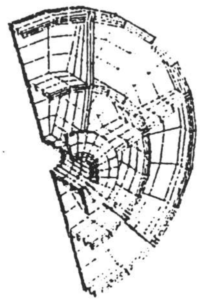
SiC Mirror Study

- Substrate Trade off
- Tooling Condition

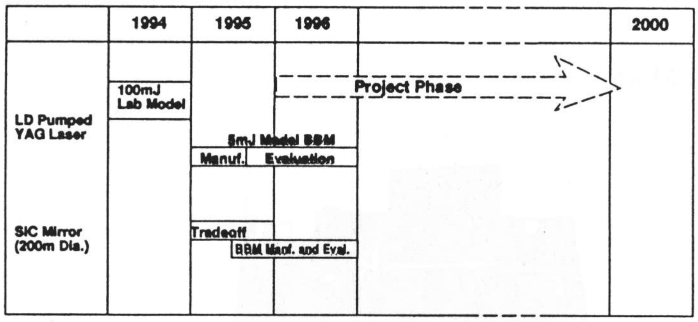


0.2 μmP－V

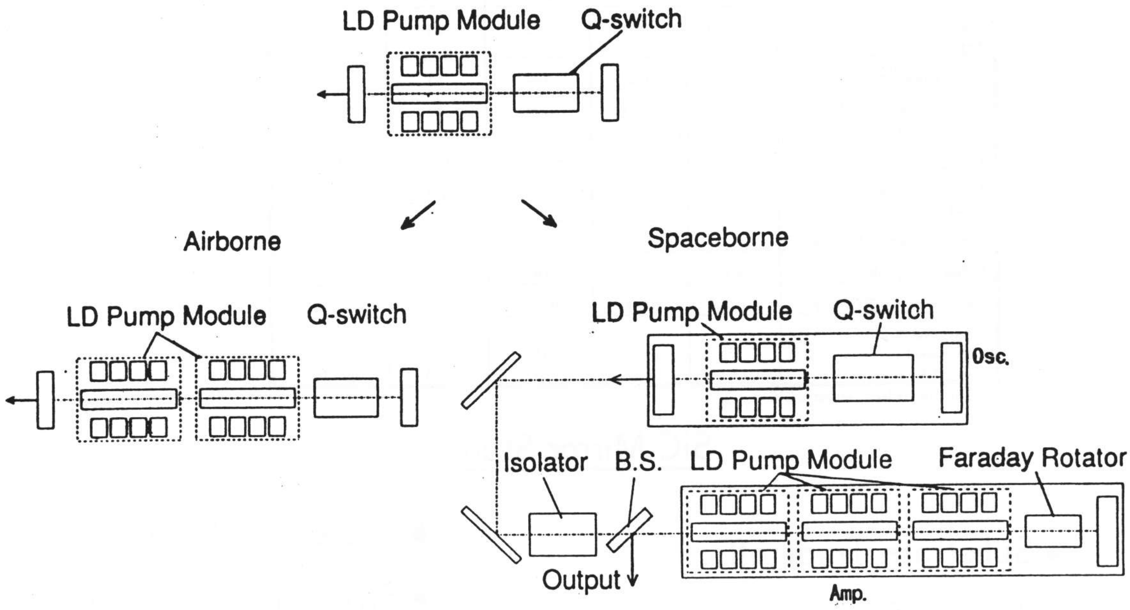
- Cassegrain layout
- Structure design and analysis



Lidar Schedule for Asteroid Mission



High Power Laser for LIDAR



Mie Lidar Approach

- High power laser
  - LD-YAG module basic design was completed.
  - MOPA configuration for high power output.
  - Heat transport by conduction cooling.
  - Temperature control of LD/YAG module.
  - Space qualified higher efficiency power supply.

Mie Lidar Approach

- Large aperture light weight SiC primary optics.
  - Major technical issue for lidar will be resolved in asteroid mission lidar.
  - Light weight structure.
  - Manufacturing Capability evaluation up to 1 meter mirror.
  - Goal: 1 meter class primary mirror with weight of 25 kg to 75 kg.

Conclusion

- Toshiba will have fully capability to develop Mie lidar from optics, laser and other component to system.
- The new technology will be demonstrated by asteroid mission lidar in near future.