Miniature multiple-axes adaptive optics unit employing SIDMs and its application to an efficient green laser module

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Abstract

An adaptive optics (AO) with a miniature micro-actuator is developed, using the smooth impact drive mechanism (SIDM), for the adjustable sub-micron alignment of the optical systems in multiple-degrees of freedom (DOF). With its unique characteristics of SIDM, the AO tunes in less than one tenth of micron resolution, yet provides over a couple of hundred micron moving range and maintains the position with little electrical power consumption. One of the most important applications is found in coupling the light from an IR-LD to SHG waveguide device in the synthetic laser configuration. The efficient compact green laser (<0.7cc of volume) is demonstrated with the AO. The use of adaptive optics helps to provide more than 100 times the tolerance in the placement accuracy of components in the assembly. This lowers the cost of manufacturing and helps maintain the optimum coupling over operating temperature, life and external perturbations without the use of power-hungry thermo-electric cooler (TEC) device.

1 Introduction

In the era of mobile & digital IT society, we are surrounded with high-tech gadgets in our daily life and business such as CD/DVD players, camera cellphones and digital anti-hand shaking cameras. It is interesting to note that actuators (mechanical devices) are the key components in these devices. It will be no exception to the emerging laser-scan microprojectors, where MEMS mirror will scan the laser beam to produce the images on the screen. We anticipate the actuator plays a key role even for the laser light source. Laser light sources for such microprojectors must be compact, efficient, and demonstrate robust and stable performance over a wide temperature range and when subjected to typical mechanical shocks and vibrations.

The basic functional elements and performance of this architecture have been presented elsewhere 1). We present the architecture of multiple-axes actuators for adaptive optics and its applications to the green laser so that it satisfies all of these laser light source requirements with the use of it.

In this report, the adaptive optics utilizing SIDM actuators as intra-module lens translation stages demonstrate the base performance over the range of operating conditions to which mobile devices are subjected by consumers. SIDM is the piezo-electric based ultrasonic linear actuator and is small enough to assemble into compact multiple-axes unit 2). The adaptive optics unit, in addition to solving a demanding operational challenge, will also enable cost-effective assembly suitable for a high-volume consumer electronics application. According to an independent market study, the embedded microprojector market such as cell-phones, game consoles

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and portable DVDs, is projected to top 150 million units by 2016 4).

2 SIDM and adaptive optics

Optical equipment typically requires a fine and accurate components alignment. An effective solution to it is to use AO. This involves mounting the lenses on actuators such that they can be translated in orthogonal directions and perpendicular or parallel to the light propagation direction. The AO devices move the lenses to ensure that the laser beam is imaged onto the waveguide facet for the best coupling as shown in Fig. 1. The DOF is at least two and preferably three or more.

Among the various actuators available in the market, as listed in Table1, piezo-based SIDM is the most suited one for the applications. It addition to its small size, it has powerful thrust and mechanical rigidity to support the optics

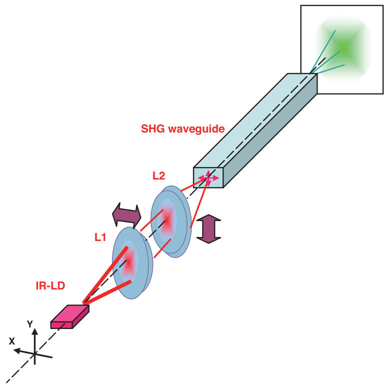


Fig.1 Schematic of the adaptive optics to couple LD to waveguide. L1 lens moves in x-axis while L2 in y-axis to scan the focus point on the waveguide input plane.

The AO should have a fine resolution as well as a wide tuning range to ease the component placement accuracy requirements.

The SIDMs have sub-micron step size with sufficient motion range to cover the expected mechanical variations, and consume minimal power to operate. Additionally, the technology is field proven and has found applications in various consumer electronics products. For instance, SIDMs auto-focus the lens in a cell phone embedded camera unit or dither the image sensor in the digital reflex camera to compensate for the user's hand shaking.

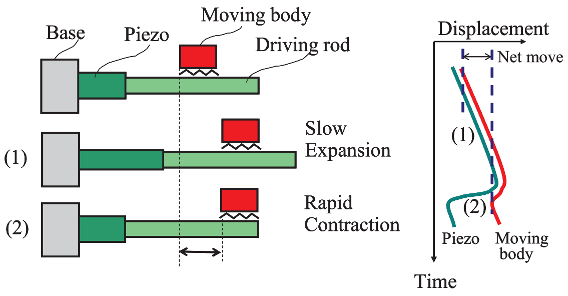
Table 1 Various actuators and their properties.

	Size	***Drive***	***Rigid***	***Resolution***	***Latch***
SIDM	*~ 5mm*	*3V*	*Ex*	*Ex*	*Yes*
VCM	~ 10mm	~ 50mA	P	Ex	No
SM	~ 10mm	~ 200mA	G	G	Yes
MEMS	~ 0.1mm	~ 50 V	G	G	No

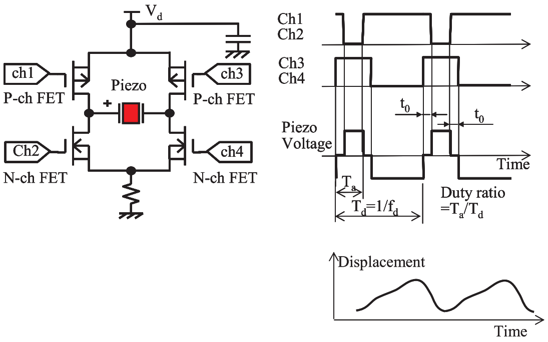
VCM: Voice coil motor, SM: Step motor, MEMS: Micro-electronic mechanical systems. Ex: Excellent, G: Good, P: Poor

3 SIDM structure and operation

The SIDM generic structure is shown in Fig. 2 (a). It consists of a piezo element (PZT), base, driving rod, and a moving body which holds the rod with friction force 2). The lens is attached to the moving body. To displace the moving body, PZT needs to expand and contract asymmetrically like the saw-tooth waveform shown in the figure. This is achieved by applying a rectangular waveform with a given voltage, frequency and duty cycle to the PZT. On the gentle upward slope of PZT, the rod carries the moving body with it under friction ("stick" operation).



(a) Basic construction and operation of a SIDM device. The slow expansion (1) and rapid contraction (2) provide the "stick" and "slip" functions, respectively.



(b) H-bridge circuit to drive SIDM. The small duty rectangular voltage across piezo translates to sawtooth vibration waveform for SIDM motion.

Fig.2 SIDM operational mechanism (a) and an external circuit to drive it (b).

On the rapid falling slope, the moving body cannot follow the rod and “slips” by inertia. The net displacement of the moving body over one stick/slip cycle is the minimum displacement for SIDM. This cycle is repeated till the desired amount of displacement is achieved. The direction of the movement is switched by flipping the polarity of the applied waveform to the device. A simple “H-bridge” circuit like Fig. 2 (b) is used to drive the SIDM device. Fig. 3 shows two displacement cycles of a SIDM device as it is driven in one direction for the full stroke of and then switched in direction. The full range is about 350um. The motion is of a constant velocity, and the minimum displacement per pulse is 30 to 50nm, small enough for fine alignment. The large stroke of the device provides sufficient range for device positioning thus low cost assembly and margin for drift in optical components over temperature and life. In addition to the slip/slick motion, SIDMs can operate in a dither mode where the moving body fluctuates around its average position.

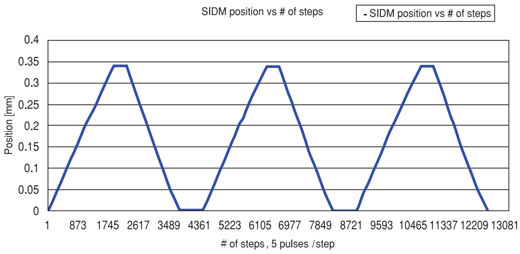


Fig.3 Plot depicting 350μm travel of the SIDM moving body. The flat portions at the end of travel correspond to the mechanical stops on either end of the driving rod.

This dither motion is used to determine the direction of the SIDM movement toward coupling peak. The SIDM device is latching in behavior and hence does not require electrical power to hold position. This implies that only a small amount of electrical power is required when the position of either of the two lenses needs to be optimized.

4 Laser structure and adaptive optics design

For the realization of micro-projector, the green laser is the key component, yet the semiconductor green laser will not be ready for sometime and the synthetic laser would fill the gap to construct efficient RGB laser sources.

The synthetic green laser architecture consists of a 1060nm infra-red (IR) laser that acts as a pump to a second harmonic generator (SHG) device, as illustrated in Fig. 4. The IR laser is a distributed Bragg reflector (DBR) ridge-waveguide laser containing three sections: Gain, Phase (ϕ) and DBR [3].

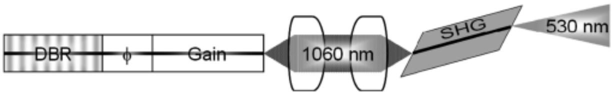


Fig.4 Illustration of Corning’s green laser architecture. Lenses L1 and L2 are used for optical coupling of 1060 nm light to SHG.

The gain section generates the IR power, and the DBR and phase sections provide general and fine IR wavelength tuning, respectively. The SHG device, which is a periodically poled lithium niobate (PPLN) waveguide, converts the IR laser input into a 530-nm green laser output through a non-linear frequency doubling process. The IR wavelength needs to be matched to the optimal SHG conversion wavelength for maximum conversion efficiency to green. The wavelength tuning provided by the DBR and phase sections of the IR laser enables high quality images to be created while the gain section is driven with a video signal, and also ensures wavelength alignment over a wide range of ambient temperatures.

A simple two lens (L1 and L2) optical system, with magnification of -1, is used to couple the light from the IR pump LD into the SHG waveguide. The first lens collimates the IR laser beam and the second lens focuses it onto the input of the SHG waveguide. The PPLN waveguide is designed to mode match to the IR laser beam and also to maximally confine the IR power to generate high intensity, thereby achieving high IR-to-green conversion efficiency. Therefore, the PPLN waveguide has cross-section of a few microns in the two transverse axes. Efficient coupling of the IR light into the PPLN waveguide requires achieving and maintaining alignment in the two transverse directions to sub-micron tolerances.

The waveguide-to-waveguide coupling presents a dual challenge for both precision assembly and robust operation. For example, a 0.3 μm shift in the PPLN waveguide in the vertical direction, which can readily be created by thermal expansion of typical materials, causes the green laser output power to reduce by 10% from the value at peak coupling. Fig. 5 depicts the variation in green light as a function of temperature for a fixed optics package where the coupling was optimized at 25 ℃ . The green power declines significantly on either side of the optimization point since the temperature-induced changes result in the IR laser beam being imaged at a point slightly offset from the center of the PPLN waveguide.

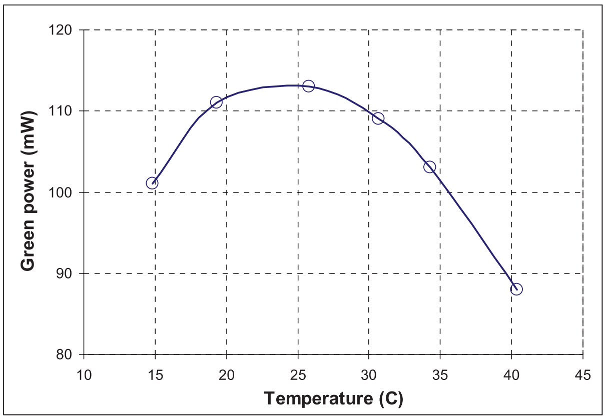


Fig.5 Change in green power over a 15 to 40 C temperature range for a package with fixed optics. The device is driven in a constant current mode.

Since the green power changes non-linearly with coupled IR power, the variation in green power is much larger than the change in coupled IR power. The green power changes by as much as 25% from 25-40 ℃ .

This variation in green power can be addressed by using a thermo-electric cooler (TEC) and stabilizing the temperature to a single point. However, a TEC is a power hungry device and is not a practical solution for use in mobile devices that have limited battery power. AO is therefore applied to solve the issues.

5 2-dim axes AO by SIDM for green laser module design and performance

A compact two-dimensional AO unit with two axes of SIDMs is fabricated, with envelope volume of about 0.1 cc. Each SIDM is driven by 3V pulses through a pair of feeders. The structure is simple with a fewer parts for mass production and inexpensive pricing. Fig. 6 (a) shows the birds view of the AO, where the lower lens moves horizontally and the upper lens moves vertically.

The green laser module is then implemented with a small form factor package design with the cavity for the AO unit. The nominal envelope volume of the device is 0.69 cc and the inside is shown in Fig. 6 [5].

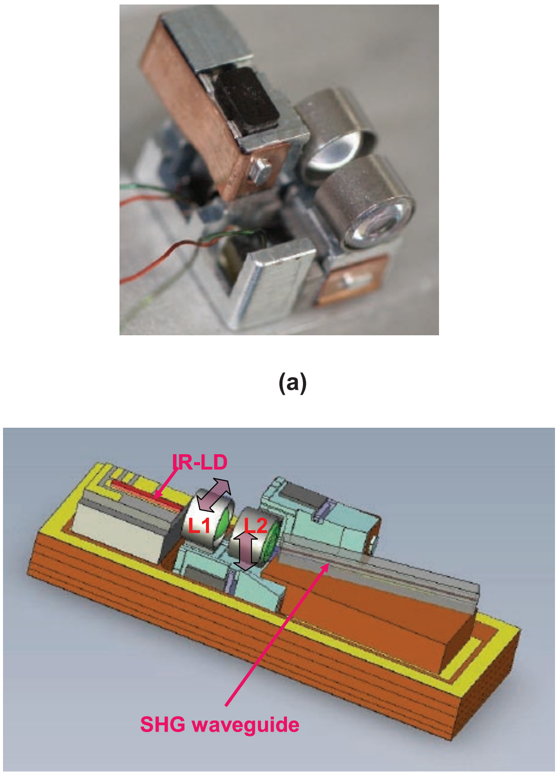
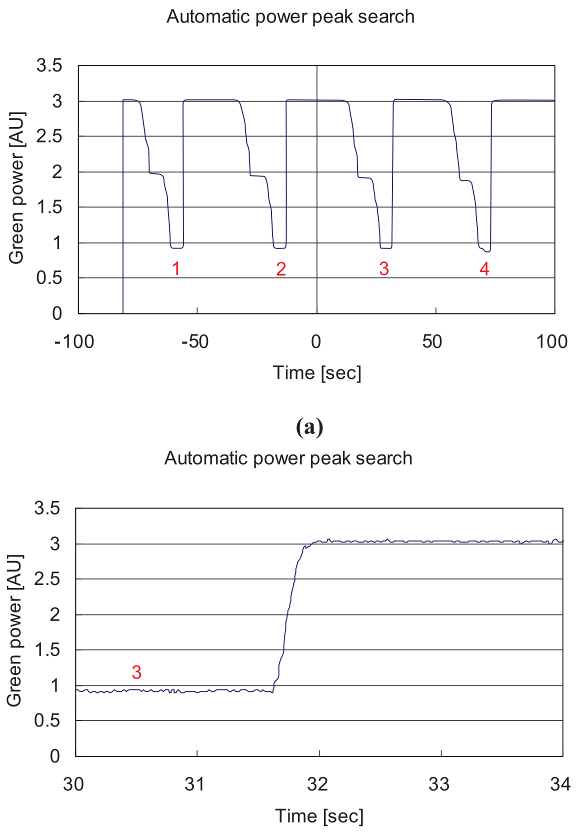

(a)

Fig.6 Photo of SIDM adaptive optics unit (a) and Illustration of green laser architecture with 2-dim. SIDM adaptive optics. Lenses L1 and L2 are used for optical coupling of 1060 nm light to SHG waveguide (b).

Pins on the side of the ceramic base provide electrical connections for operating the DBR laser and the SIDM devices. The optical components, including the DBR laser, the adaptive optics and SHG, are assembled on a ceramic base that provides electrical interconnects. A metallic lid with an optical window is used as a cover. The SHG front facet is wedged and AR-coated to minimize back-reflection to the DBR laser. The SHG is hence mechanically angled to ensure optimum coupling into the angled front facet. A similar wedge at the output facet ensures that the green output is parallel to the optical axis of the DBR laser.

The functionality of the adaptive optics to maintain optical alignment is demonstrated in Fig. 7. The SIDM are intentionally moved to produce a deliberate misalignment of the two lenses to reduce green power. Points 1, 2, 3 and 4 represent the misalignment of the optics in four different directions combination of x and y. After misalignment, a closed-loop algorithm is initiated to recover the optical alignment. As can be seen, the maximum green power is recovered in all four cases. The recovery time of less than one second from off-alignment seen here is fast enough for occasional misalignment by external shock or in the turn-on event.



(a)

(b)

Fig.7 Depiction of the ability of the adaptive optics to regain alignment through the closed loop operation. The SIDM devices are deliberately misaligned in four combinations and the closed loop is subsequently turned on to recover green power (a), and a blow-up of the rising edge at point 3.

To test the effectiveness of the adaptive optics module we placed a device on an external TEC and cycled it over a 10 to 60 °C temperature range in the constant gain current mode. Fig. 8 shows the change in green power over temperature for this module.

Compared to the case where adaptive optics are not utilized (Fig. 4), the change in power over the 25 to 40 °C temperature range is reduced from 25% to about 4% . The change in green power is 16% over the 10 to 60 °C temperature range.

The drop in power at higher temperatures can primarily be attributed to the temperature-induced reduction in IR output power of the DBR laser. The change in the axial separation between the DBR laser and SHG largely accounts for the power variation at lower temperatures.

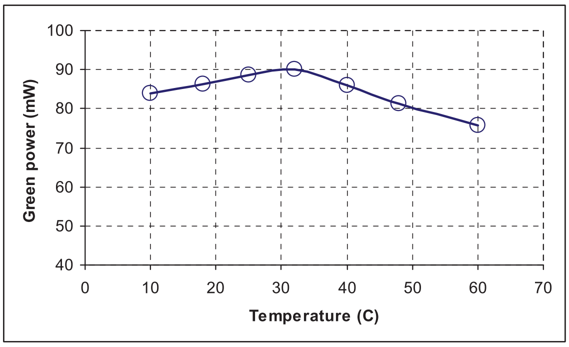


Fig.8 Change in green power over a 10-60°C temperature range for a G1000 package. An external photodiode is used to provide feedback that drives the SIDM devices. The IR laser is driven in a constant current mode.

6 Assembly tolerance and cost impact

The use of adaptive optics also helps to lower the cost of module assembly. Fig. 9 compares the placement accuracy requirement of the SHG device (in the vertical direction) during the assembly process for the fixed optics package, as well as for the adaptive optics package. As can be seen, the tolerance of alignment increases from a few tenths of microns for a package with fixed optics package to a few tens of microns for one with adaptive optics. For example, to achieve green power within 10% of the peak value the SHG needs to be placed within 0.3 μm of the optimum value for fixed optics module while for an assembly with the adaptive optics this value is almost 90 μm. This relaxation of alignment tolerance lowers the complexity of the assembly equipment and process, resulting in overall cost reduction necessary for high volume manufacturing for consumer electronics applications.

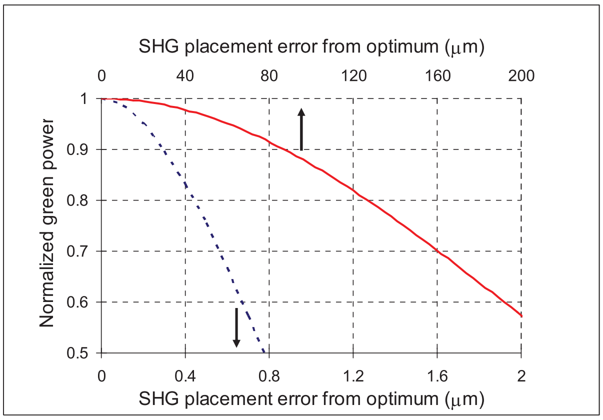


Fig.9 Change in green power as a function of the SHG vertical position from the optimum location for a module with fixed optics (dashed curve - bottom axis) and adaptive optics (solid curve - top axis).

7 Summary

We have shown that the use of 2-dimensional actuator adaptive optics is effectively used in the green laser module for the emerging micro-projector applications. The use of the waveguide in the SHG device increases the IR to green light conversion efficiency but introduces a challenge of maintaining sub-micron level alignment over temperature and lifetime. In this paper we have shown that the use of SIDM-based adaptive optics 5) provides green power stability over temperature while also lowering the cost of assembly. The SIDM device has a large travel range and can be used in conjunction with an external closed loop to provide a very fast response to thermal changes or mechanical shock. A miniature frequency-doubled green laser source (<0.7cc) using the adaptive optics configuration was demonstrated for potential applications to micro-projectors over an extended temperature range.

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