Proceedings of the ASME 2011 Pacific Rim Technical Conference & Exposition on Packaging and Integration of Electronic and Photonic Systems
InterPACK2011
July 6-8, 2011, Portland, Oregon, USA

IPACK2011-52028

A Novel Precision Die Attach Technique for Opto-Electronics Packaging

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ABSTRACT

Semiconductor Laser diodes that emit visible light have various interesting applications such as sensing, high density optical storage and projection displays. In any opto-electronic package, the laser diode chips are typically attached or soldered to metal or ceramic substrates that have good thermal conductivity and are well-matched in coefficient of thermal expansion using solder. Some applications require a critical alignment of the front facet of the laser diode to the front edge of the substrate onto which the laser diode chip is attached to. Depending on the application, the alignment precision could be varying from 20μm to being as stringent as 0.5 to 1μm. In many of these applications, the cost of packaging is also a very important factor. In such applications, it is essential to develop a laser diode chip bonding process that can meet such stringent die alignments along with a low cost manufacturing process.Therefore, the objective of this research work is to provide a low cost alternative solution for die attach process that can guarantee alignment precision of 0.5 to 1 microns and can be easily adapted to high volume manufacturing.

The novel technique proposed in this work uses primarily gravity force for the facet alignments between the two components. In this passive-gravity assisted precision (P-GAP)assembly process, the laser diode (LD) chip is placed on the substrate using a traditional pick and place machine and later the substrate and the chip are tilted such that the chip slides on the substrate due to the gravity and touches a mechanical stop in-front of them. This does not involve any active alignment. In addition, we have provided few ideas to improve the sliding when gravity is used.This technique has been implemented on several samples and the feasibility of achieving the alignment precision to within a micron was demonstrated.

KEYWORDS

Laser diode, Die attach, Opto-electronics Packaging, Gravity, Precision Alignment.

INTRODUCTION

Semiconductor Laser diodes that emit visible light have various interesting applications such as sensing, high density optical storage and projection displays. In addition, high power laser bars are used in material processing, medical and free space communication systems. Of specific interest to this study, is the application of laser diodes in micro-projection displays. The capacity of high speed wireless networks has enabled carriers to provide multi-media services to consumers such as web-browsing, live television, gaming etc. At the same time, the electronics industry is driving towards miniaturization which in turn has led to the smaller size of displays on the electronic devices. The smaller display limits the full utilization and enjoyment of these services. Micro-projectors have been proposed to address this issue[1]. The micro-projector technology has two major components in the optical engine: 1) Light source 2) Imaging technology. Optical engines are modules that combine the red-green-blue (RGB) light sources and an imaging element or elements. Three primary colors, red, blue and green are required to create full color images. Red and blue lasers are commercially available for applications to the optical read/write products such as DVD players whereas green has been a challenge to produce through currently available processes and materials. A green laser is often referred to as the "keystone"component to enable laser-based mobile

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projection. Extensive research has been conducted to develop native green lasers using either III-V or II-VI compound semiconductors. Recent technological advancements have led to creation of native green laser light by Sumitomo, Osram and others. For instance, Sumitomo succeeded in producing 2.4 mW of optical power at 520 nm at room temperature continuous wave lasing of InGaN-based green LDs on semi-polar GaN substrates[2]. Native green lasers are easier to control, and could potentially demonstrate greater temperature stability, a smaller form factor and higher modulation capability at several 100 MHz. However, there has not been sufficient reliability data of these devices under operating conditions. While the native green lasers are under development, a synthetic green laser has already been developed by various companies such as Corning[3]. It is based on frequency doubling of 1060 nm IR light emitted from a semiconductor laser diode (LD) chip, using second harmonic generation (SHG) crystal. As a next step towards making low cost synthetic green laser, it is proposed to use proximity coupling approach where in the SHG structure is brought in close proximity to the LD, thereby eliminating the use of any optics in between [4]-[5]. The proximity coupling approach reduces the number of package components and process cost significantly. Figure 1 below shows the schematic of a proximity coupled package that can generate green light. As shown in the figure, the laser diode (LD) is in close proximity to the SHG. The distance between the waveguides of LD and SHG is less than 5μm.

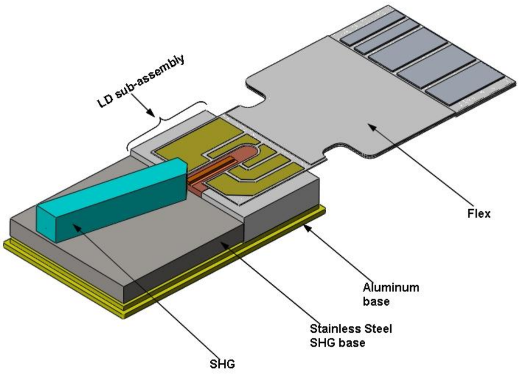

Figure 1: Proximity Coupled Synthetic Green Laser Package

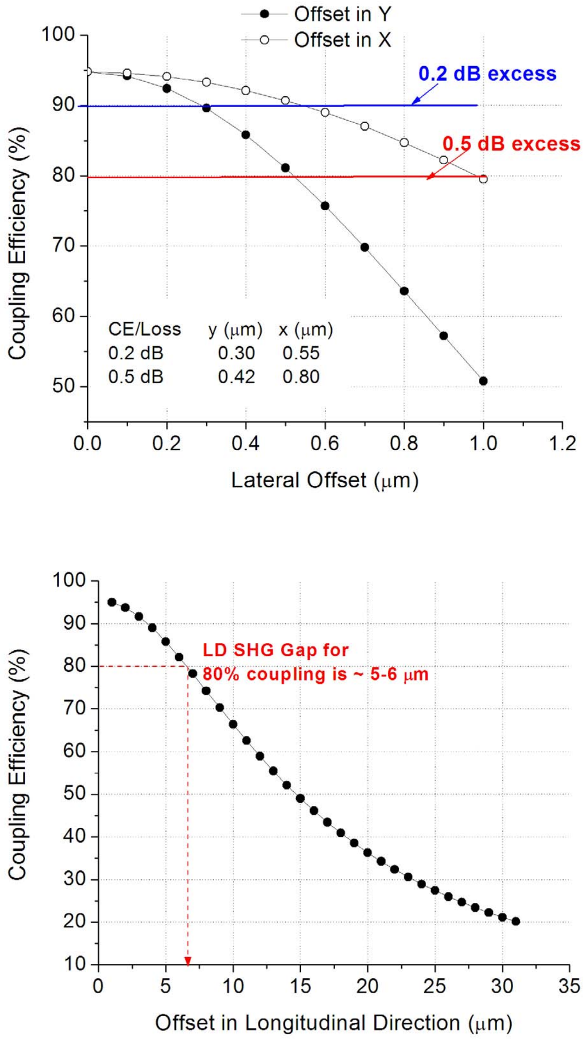

Figure 2: Coupling Efficiency Vs Mis-alignment in X, Y and Z Directions

The biggest challenge in this approach is alignment of waveguides of laser diode and SHG. Figure 2 below shows the coupling efficiency curve as a function of mis-alignment of the waveguides. It is evident from the figure 2 that the alignment in x, y and z directions is very critical for proximity coupled synthetic green laser. It can be noted that the distance between LD and SHG waveguides should be less than 5μm for 85% coupling efficiency. The laser diode is typically soldered to metal substrates that have good thermal conductivity and well-matched in coefficient of thermal expansion using solder. Commercially available die-attach machines or die-bonders can align the chip to the substrate easily within 10 μm at 3σ conditions [6]-[9]. Some vendors claim that their machines are capable of aligning to 1.5 μm at 3σ[6]. However, this equipment may be too expensive for some applications. In addition, in such machines, if the alignment precision requirements are very tight, the throughout decreases significantly and therefore, manufacturing cost increases. There-

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fore, the objective of this research work is to provide a low cost alternative solution for die attach process that can guarantee alignment precision of 0.5 to 1 μm and can be easily adapted to high volume manufacturing. While the current work presents the embodiments pertaining to proximity coupled synthetic green laser package, the idea can be applied to various applications that require this kind of accuracy.The next section presents passive gravity assisted precision die attachment technique.

DESCRIPTION OF THE METHOD

Typically, the assembly process starts by inspecting the laser diode chips to make sure that the front facet of the laser diode does not have any metallization issues. If the metallization on the P-side or N-side of the laser diode chip protrudes out, it affects the alignment precision. Figure 3 below shows an example of protrusions on the alignment side. This is important criteria during the selection of the chips for the assembly. The fixture that holds the chip and the substrate during the assembly process is shown in figure 3. The design shown in Figure 4 is an example. Several design modifications can be made to achieve the same task. The groves shown in the Figure 4 are the locations where the metal substrate and laser diodes will be placed. The mechanical “stop” indicated in Figure 3 is recommended to be made up of glass. Glass provides a clean, flat surface for the stop. Also, glass doesn’t stick to the LD facet or the solder while the die is being soldered. This also ensures the perfect flat surface against which the laser chip and the substrate stop. This stop can be held in place by the vacuum or mechanical clips or spring loaded means. The mechanical clips may be more suitable for high temperature operation needed for soldering in ovens, whereas the vacuum may be more suited in a localized heating arrangement. As the name indicates, the purpose of this component is to act as stop for the chip and the metal substrate during the process.

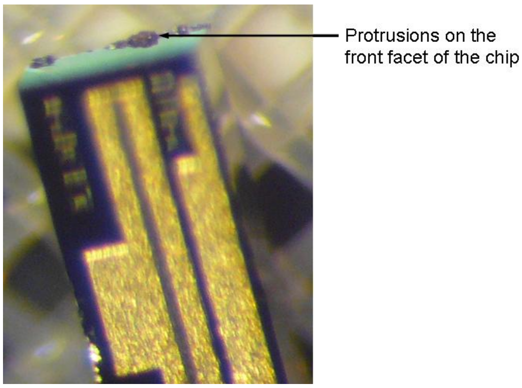

Figure 3: Protrusions from the Front Facet of the Chip

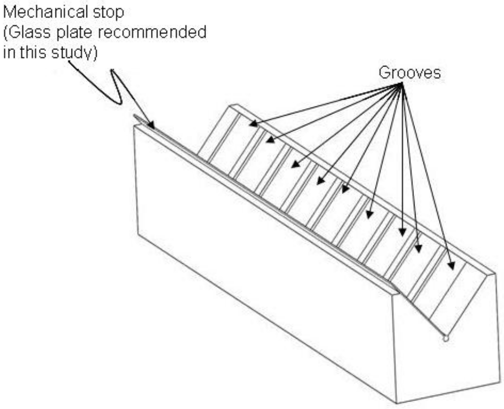

Figure 4: Fixture used in the P-GAP process

Once the laser diodes are inspected, next step is to pick the metal substrate with a conventional pick and place machine and placing the substrates in the groves in the fixture. The fixture shown in figure 4 is rotated approximately 80^o-90^o such that the grooves are flat with respect to the tool, see Figure 5. The included angle ‘a’ of the fixture shown in the figure 5 needs to be controlled very precisely to be equal to 90^o for submicron facet alignment. Otherwise, the LD chip would project beyond or recess behind the metal substrate facet depending on whether the angle is greater than or less than 90^o. The extent of this projection or recession depends on the stack height. This feature may be used not only to get facet alignment to submicron accuracies but if needed to position the LD with a known and controlled amount of pro-

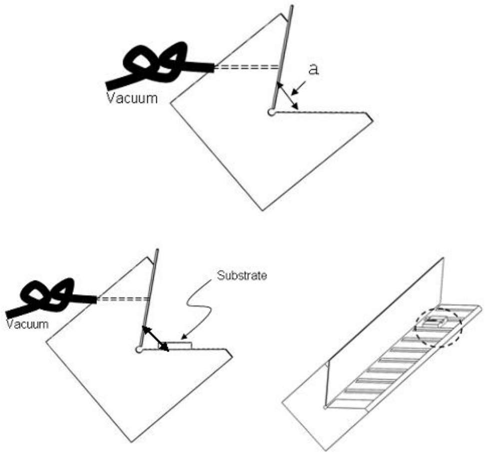

Figure 5: Rotation of the Fixture and placement of the Substrate

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jection or recess. The "stack" here refers to the metal substrate thickness on which the laser diode sits. In this particular scenario, it is the only component. In other instances, there can be multiple components attached to each other and the whole stack can be referred to as substrate onto which the laser diode will be attached to.

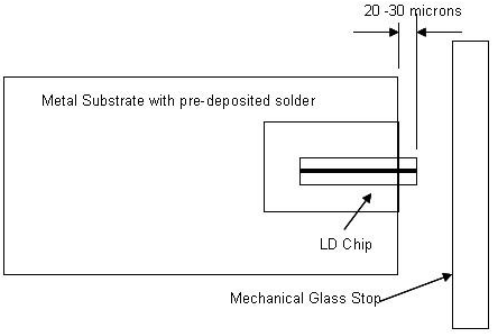

Figure 6: Schematic (Top View) showing the chip placement requirement on the substrate

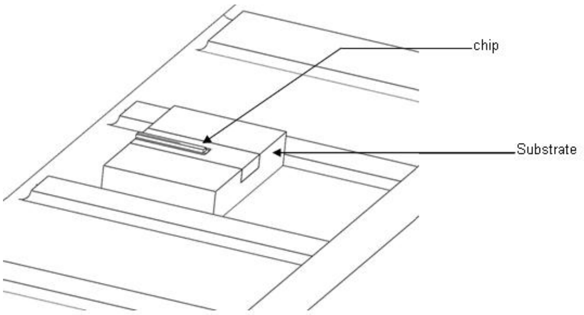

Figure 7: Placement of the Chip on the Substrate

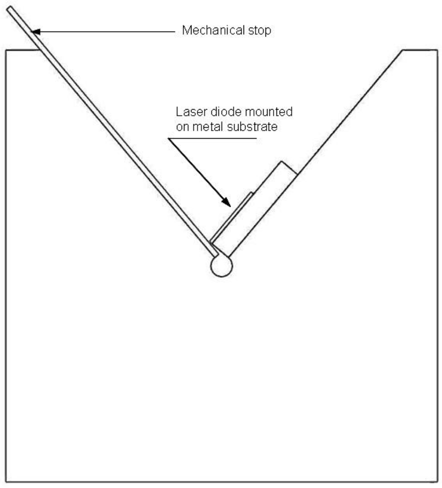

Figure 8: Final Position of the Fixture and Chip on Substrate

Later, the laser diode chips are picked using the same machine and are placed on top of the metal substrate. Care must be taken such that the laser diode chips are projecting out about 20-50 μm from the metal substrate facet, see Figure 6. The angular orientation of the LD with respect to the metal substrate facet needs to be 0.5-1^o or better. The LD needs to be placed close to the center of the pre-deposited solder area, See Figure 7. These placement requirements are within the capabilities of current high throughput pick & place equipment that are commercially available. Once the substrate and the chip are placed as described above, the entire fixture is tilted so that the chip and substrate slide forward until they touch the mechanical stop. See Figure 8. Generally, the LD chip is quite small (in this study, the chip is 3 mm long, 0.3 mm wide and 0.15 mm thick) and has very little weight compared to the metal substrate. Hence the gravity force on the LD chip alone may not be strong enough to overcome the friction between the LD chip and metal substrate. By positioning the LD chip to project out a few microns in front of the metal substrate overcomes this problem. When the fixture is tilted, both the LD chip and the metal substrate slide towards the "stop" and the LD chip comes in contact with the "stop" first and the front facet of the LD chip is aligned accurately against the flat surface of the stop. As the metal substrate is heavy enough to overcome any friction between the LD chip and substrate, the metal substrate continues to slide down till it also come to a rest against the "stop". By this process both the front facets of the LD and metal substrates are accurately aligned with out any active alignment. Key advantages of this process are: 1) the accuracy of alignment is not degraded by any "rounding"of the facet edges of the metal substrates. Therefore, there is no necessity for precise machining of the metal substrate edges, 2) the roughness of the facets also doesn't impact the accuracy of alignment. This robust and passive alignment even with such substrates is a significant advantage of this process compared to any active alignment based on vision systems. In vision systems, the front facet edge rounding can cause uncertainty in determining the location of the facet edge and cause reproducibility problems, 3) the force applied on the facets when they slide to the "Stop" surface is gentle and hence the fragile LD facets are not damaged.

The following precautions have to be taken during this process: 1)no dust particles or unwanted protrusions on the front facets of the LD chip and the substrates. Such problems would prevent the

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front facets from coming in full contact with the "stop", 2) alignment is not disturbed during the tilting of the jig or during the loading into the oven, 3) the parameters for soldering process has to be chosen to make sure that there is no "pooling of the solder" at the front facet, but allow good bonding and further, the bonding have to be good enough that the LD doesn't move during the wire bonding or operation.

Various options are plausible for soldering process in high volume manufacturing. Several of these fixtures can be made with as many grooves as possible. Once the laser diode chip and the metal substrate are in place, the fixture can be hand carried and placed inside the solder reflow oven. Another possibility could be the fixture is mounted onto a conveyor belt and once the laser diode chips and substrates are aligned, the belt will move the fixture into the solder reflow oven. Several parts were assembled using this approach and the alignment obtained from 15 samples are shown in the table below. These samples do not make a single lot but come from multiple lots of various sizes. Data representative of different observations made during this experiment is presented in the table. It can be observed from the data in the table that the average value of alignment obtained from this assembly process is 1 μm. The range is found to be from 1 μm to 4 μm from this set. It must be noted that alignment values obtained from samples 12 to 15 are not accounted for in the estimation of average value. This is because the laser diodes in those samples have n-metal protrusions on the alignment face as shown in the Figure 3. The length of these protrusions are same as the alignment obtained from these samples. This proves that the actual alignment is within the expectations of this assembly process. Reasons for the alignment obtained in the case of B23-25 and B49-05 are not clear; however, it could be due to the uncertainty in the planarity of the metal substrate. If the alignment surface of the metal substrate is not planar and has an angle through its thickness, it might result in the overhang of the laser diode. Figure 9 through Figure 11 show pictures of actual assembled parts and their characterization methods and results. Figure 8 shows a top view microscope picture of a 1060 nm DBR laser diode aligned and bonded onto a steel metal substrate using P-GAP approach. The front facets of the LD and metal substrate can be clearly seen to be very well aligned.

Table 1: Alignment Accuracy in some of the Assembled LD Sub-assemblies

Sample#	SampleID	Alignment(μm) '+' overhang, '-' Recess
1	B49-08	1
2	B49-09	-1
3	B49-10	-0.5
4	B49-11	0
5	B49-14	1
6	B23-01	0
7	B23-07	0
8	B23-25	2.5
9	B23-23	0
10	B49-08	1
11	B49-05	4
12	C39-02	-8
13	C39-06	-8
14	C39-03	-10
15	C39-04	-13

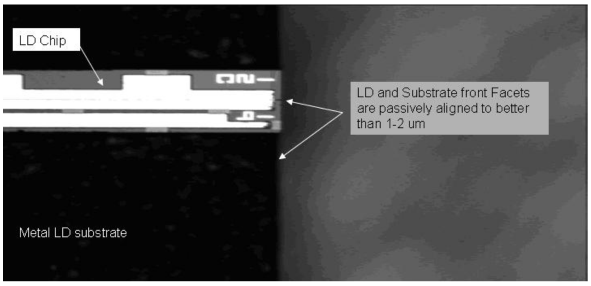

Figure 9: Example of an LD Sub-assembly made by the P-GAP process

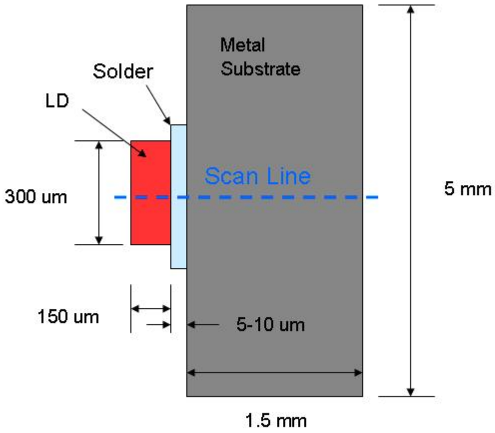

Figure 10: Schematic of the End-on-View of the LD Sub-assembly and characterization of the contour along the scan line

In figure 10, a schematic of the characterization technique used to quantify the facet alignment is

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shown. In this end-on view, the laser diode and substrate facets are shown along with a scan line along which a contour of the sub-assembly is obtained using a Keyence laser scanner. The laser scanner has a resolution of better than 100nm. Figure 10 shows a scan result obtained using such a characterization technique.

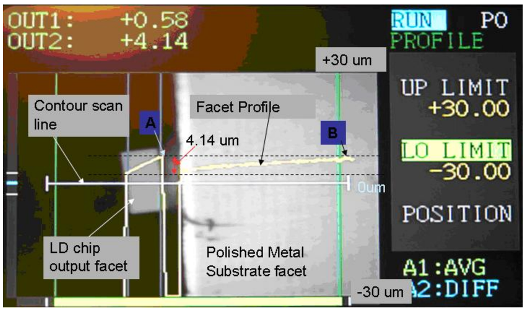
OUT1: +0.58
OUT2: +4.14
RUN PO
PROFILE
UP LIMIT +30.00
LO LIMIT -30.00
POSITION
A1:AVG
A2:DIFF

Figure 11: Experimental Characterization of the LD facet alignment with substrate facet using Keyence laser scanner

The various parts of the assembly are identified in the picture along with the position of the scan line and the facet contour profile. The contour profile of the facets is superimposed on the facet image in this picture. As can be seen, the LD facet has tilt and the bottom edge (one nearest the substrate) is identified as point 'A'. Similarly, the highest point of the substrate facet is identified as point "B". These two points are measured to be in alignment to better than 0.58μm as measured by this technique. The alignment of the laser diode front facet with respect to the metal substrate front facet is measured and found to be less than 1μm in almost all the assemblies. These results indicate that the technique is demonstrated on a GaAs based laser diode chip mounted on a metal substrate. This technique can be applied in any application that requires a critical alignment of the chip with the substrate. As indicated before, this technique can be used not only to get submicron facet alignment, but also to get a controlled projection or recess by changing the angle 'a' of the fixture and the stack height of the subassembly. Another variation that can be considered is the "oblique P-GAP". In this case, the facet alignment can be done on two planes. This can be achieved using two "V-blocks" to slide the parts in an oblique plane and having two "Stop" planes. An example of such fixturing is shown in figure 12. Such features are useful if the chips need to be precisely positioned on the metal substrates while aligning the front facets. Such techniques can also be used to mount the chips at a precise angle on the substrate while aligning the front facets. For example, for assembling SHGs for green laser proximity packaging, the angle polished SHG need to be oriented at an angle to minimize the back reflections. This technique can potentially be used in such cases also.

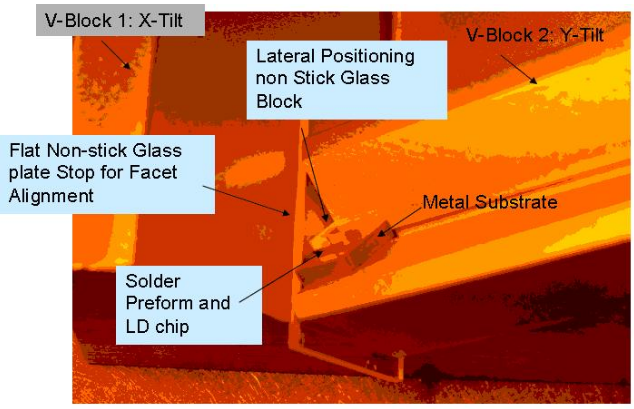

Figure 12: Passive-Gravity Assisted Precision (P-GAP) Fixture for 2-facet alignment

There are other types of driving forces that can be used to bring about the needed facet alignment. Examples are spring loaded or vacuum fixtures that slide the chips up against the "stop" surface. One such embodiment is shown in figure 13. The figure shows that the SHG is held with just enough vacuum required to hold the SHG at required angle. The objective is to align the SHG front facet with the front facet of the metal substrate on to which it is attached. The SHG that is being held with vacuum will "slip" back when it touches the mechanical stop if the force applied on the chip as it contacts the "stop" surface is greater than a set value. This results in very precise alignment of SHG with the metal substrate. Once the SHG is aligned, it will be attached to the metal substrate using UV cured glue or soldered if possible. Such variations based on the general concept disclosed here can be useful for a number of precision alignment applications.

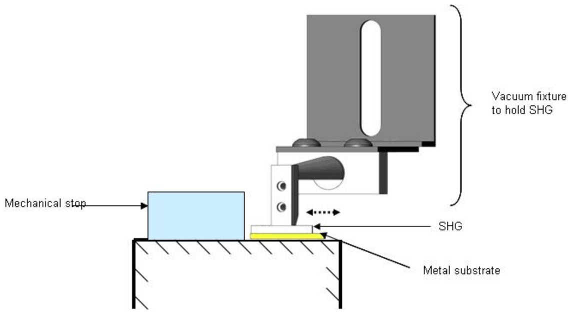

Figure 13: SHG Assembly using Vacuum Fixture

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CONCLUSIONS

A novel precision die attachment technique based on the gravity is proposed in this work. This technique helps in the aligning two opto-electronic components to within a micron. Detailed description, fixtures involved, characterization of the samples assembled using this method are presented in this paper. Various techniques to improve this process are provided. It must be noted that this process technique is still under progress to be readily adopted into high volume manufacturing environment.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Christopher Page for his help in sample preparation.

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