A Fast-Result Method of Planar Polishing for Optical Microscopy

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The planarizing technique of materials lapping and polishing shows many benefits in providing samples for optical microscopy in failure analysis, quality control and related fields. A method is described below which provides both rapid and accurate micro-sections of pcb's, wafers, packaged components and other processed materials, with the use of a novel approach involving a 'calibrated' polishing base and a 'Micropositioner' head. Other benefits include the ability to halt material removal at a predetermined process endpoint and convenient sample mounting techniques.

PLANARITY IN TRADITIONAL LAPPING & POLISHING TECHNIQUES

Planar polishing is defined as the polishing of a relatively large surface on a relatively short workpiece. Such a workpiece is likely to be described as a "disc" or a "wafer", giving an idea of the typical proportions of the surface to the length of the workpiece.

Planarity in traditional lapping and polishing processes is maintained with the use of a conditioning ring arrangement, on a machine which incorporates a suitable controlled reciprocating roller-bar mechanism and conditioning rings. The method of controlling plate flatness is shown in Fig. 1

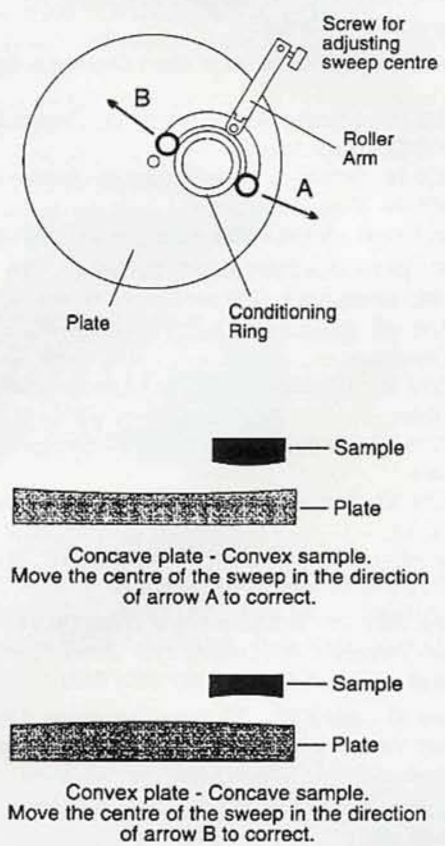

Figure 1 - Techniques for Maintenance of Plate Flatness in Traditional flat Lapping Techniques

The use of a Precision Polishing Jig (as illustrated in Fig. 2, and as described in UTTN088[2]), which incorporates a conditioning ring, offers the ultimate accuracy in flatness and parallelism. But, by its nature, the preparation process is slow.

THE PLANAR POLISHING APPROACH - A FAST METHOD

There are circumstances in which small errors (of perhaps 5 µm cm^{-1}) in absolute flatness are tolerable, in exchange for fast results and there is a method of obtaining these relatively fast results: by using a Planar Positioner in which the workpiece is held against the lapping surface so that only the workpiece itself makes contact, and makes contact in such a way that the removal of material proceeds rapidly.

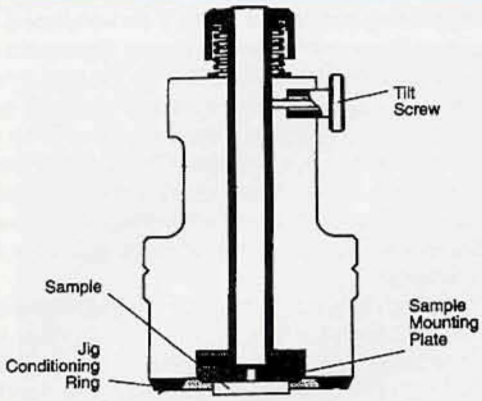

Figure 2 - Precision Polishing Jig

As compared to the Precision Polishing Jig, which holds the workpiece and 'rides' the lap in a co-dependent unitized system, the Planar Positioner is independently located next to the rotating lap, thus introducing a degree of *freedom. This is the source of the flatness error, which, with accurate equipment,* can be maintained at a small tolerable level.

A system to perform fast-result planar polishing requires:

(1) a base, with a true-running mechanized rotational lapping surface, and,
(2) a firm Planar Positioning device (as shown in Fig. 3), which includes:
 (a) an accurate Z-direction linear positioning feature, and
 (b) provision for controllable pressure against the workpiece relative to the lapping surface,
 (c) which is aligned for parallelism in relation to the lapping surface, as it holds and imparts a rotational action to the workpiece, and
 (d) which allows the workpiece to move downward, as material is being removed, through a small section of a relatively large arc as the final desired flat condition is approached.

Comments and explanations of these required characteristics follow:

In Regard to the Base

In this fast-result system, the lapping surface is held accurately in relation to the Planar Positioner by a shared reference surface[1]. The reference surface is a flat plate that is parallel to the surface of the lap, and on which the Positioner stands - which, along with the various electrical controls, constitutes the "Base".

Since the Planar Positioner will hold the workpiece parallel to the lapping surface, any rotational runout of that lapping surface (up and down dimensional variation when measuring the rotating surface) will reflect as an error on the workpiece. Maintaining that runout at a minimum, therefore, is important.

Using a 20 cm diameter lapping disc, it is reasonable that the runout can be held between 1 and 2 $\mu m\ cm^{-1}$, an amount which is usually "tolerable" on the typically small specimen. Runout is the most apparent, but not the only source of error, of course, and so it is important to keep the runout minimal - being sure that the undersurface of the lapping disc is clean when the disc is mounted.

Better runout is possible (but may more often be claimed than delivered). Improved runout may become a necessity for larger specimens for which a fast-result technique is itself a necessity, not allowing for the more lengthy planar polishing techniques. To obtain such improvement requires special attention in setting up the machine, one major technique being rotation of the lapping disc on its platen so that the errors of those elements tend to offset and cancel[2].

In Regard to the Planar Positioning Device

The Planar Positioner is an equally critical component of this system, the very technique being defined by the use of an independent work positioning device in relation to an independent lapping surface.

Aside from the required firmness of the Positioner, its inclusion of a Z direction control, provision for applying pressure to the workpiece against the lapping surface, which are characteristics of any sort of polishing system, the accuracy of the rotating element - the workholder to which the workpiece is attached - is of prime importance.

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... Planar Polishing ... Continued from preceding page

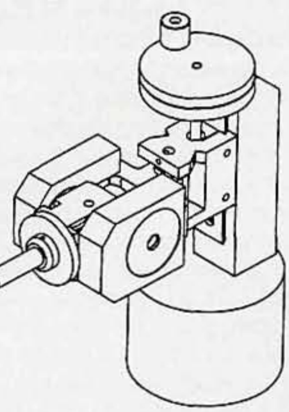

Figure 3 - Schematic of the Micropositioned Polishing Head

Similar to the opposing lapping disc, the rotating element of the Positioner must rotate with a minimum of runout, and as in the case of the lapping disc, that accuracy is a matter of equipment construction. As a practical matter, the construction of the Workholder rotation element, similar to the rotating lapping disc, would have a runout of 1-2 μm cm^{-1}. It is worth noting that the runout errors are not strictly additive, given that the rotation of the lapping disc and the rotation of the workholder are randomized in relation to each other. The workholder both oscillates over the lapping surface and rotates in out-of-phase speeds (for example, the workpiece may rotate at 10 RPM and the lapping disc at several hundred). Ideally, both speeds would be variable, which would be useful in optimizing the results.

The Positioner must include an adjustment for the parallelism of the workholder relative to the lapping surface. This adjustment would allow for the "zeroing-out" of tolerance errors introduced by a workholding plate, and other random errors introduced in the setup process, so that their contribution to the overall error can be minimized. In this system, with only the workpiece itself in contact with the lapping surface, rapid operation is important. The last mentioned characteristic of this system, with the final flat condition reached by the lowering workpiece moving though an arc as it rotates, is the most significant contributor to speed. This is perhaps most easily explained by resorting to an analogy with which most people are familiar: the slicing of a rotating part. It is common experience that cutting is quickest if the workpiece is rotated - ideally, 360° rotation would make the operation fastest. The reason is as the blade passes though a rotating workpiece, only a small tangerntial area (theoretically a point) is being contacted. By contrast, if the workpiece is not rotating relative to the blade, a very long surface of contact between the blade and the workpiece develops and the blade needs to work very hard (compounded by the mechanical properties of the sample), and can possibly stall. With rotation, the blade is not working very hard to overcome the resistance of the workpiece and the task becomes easy, which translates to high speed.

In grinding/polishing material from a disc, if the workpiece is rotating and lowering through an arc, something similar happens. The contact between the workpiece and the lapping surface corresponds to a line. Not quite as nice as the point contact of the sawing analogy, but still, a very small section of the workpiece is in contact with the lapping surface, and the operation can proceed quickly. Due to the relative rotational motions of the lap and the planar polisher, the work interface moves through a cone shape, a continually flattening cone, until the desired preset removal of material is complete, and the cone flattens out completely. The very last stages of the operation are against that flat surface - with little work remaining.

It is worth understanding that the nature of the planarity error in this sort of "fast-result" system is different from that of the traditional Precision Jig on-the-lap method. Any error, that is, any departure from absolute planarity, will be conical: higher measurements in the center of the rotation and progressively lower toward the perimeter of the workpiece.

There are two additional characteristics of the Planar Polisher which are worth noting:

1) There is a STOP mechanism which signals completion and halts the polishing action. This signals the operator to attend to other tasks since not attending to the planar polisher would NOT result in the over polish of the workpiece, and
2) On the Planar Polisher, the mounting plate which holds the workpiece can be removed and remounted so that a following workpiece can easily be mounted while the positioner is still working on a prior workpiece. Also, this feature allows the operator to remove the workpiece on its mounting plate for microscopic examination, and then remount it if further material removal is required. This benefits failure analysis type applications where, for instance, several polishing iterations may be required to remove several coating layers (one at a time) or to view possible sources of component failure at differing depth positions.

These latter features are standard on the Planar Polisher. They are not necessarily unique to that device - they could be added to the Precision Jig, but not easily and not without considerable added cost.

CONCLUSIONS

The 'fast-result' planar polishing system is advantageous when the on-going need is for quick results, such as in quality control operations, or, when the requirement just doesn't need the virtual "no-error" accuracy that the Precision Polishing Jig approach provides. So, it represents an acceptable compromise, in the interest of practicality for the busy modern laboratory. This approach is also significantly less costly from an equipment cost standpoint, another practical matter in many cases.

Since different sizes of material, and different types of material are involved, and until a particular process is well defined, the operator should experiment (primarily with speeds, pressures, and with the nature of the lapping surface itself) to obtain optimum results. Typically the use of lapping films with electrostatically-coated diamond or oxide/carbide fixed abrasives provides the most convenient and accurate surfaces.

In terms of the accuracy in planarity that the process provides, several of the error sources have been discussed above, and, there are, of course, various additional random errors. Empirical results have confirmed typical total errors of less than 7 μm across workpieces of approximately 1.5 cm square, and using the statistical data available, 95% of results < 10 μm.

Can an operator work with this system and obtain better results? The answer to that is an almost self-defining *yes*. But, if *better* is what is needed (and *slower* can be tolerated), it would be *better* to use the traditional slower methods.

There are industrial operations where the sort of planarity provided is much more than adequate, and for those, the speed advantage becomes obvious. ■

Footnotes

1. Very much like the common design of a milling machine that may have a secondary positioning device added to the workholding surface.
2. An interesting case can be made for a purposeful error in the platen so that is available to offset the error of the lapping disc.

Bibliography

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