PRECISION ENGINEERING

B.TECH. V SEMESTER
MECHANICAL ENGINEERING

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UNIT – I

ACCURACY AND ALIGHNMENT TESTS

ACCURACY

- Accuracy of an instrument is the extent to which the average of a long series of repeat measurement made on the same unit of product differs from the true value of the product. The difference between the true value and the measured value is known as error of measurement.
- The power transferred is Work piece: The following factors affect the accuracy

1. Cleanliness surface finish etc.
2. Surface defects
3. Hidden geometry
4. Thermal equalization etc

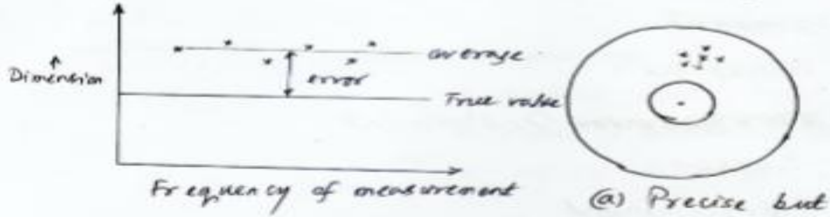
What is Precision?

- Precision of an instrument is the extent to which the instrument repeats its result while making repeat measurement on the same unit of product. It is the repeatability of the measuring process.

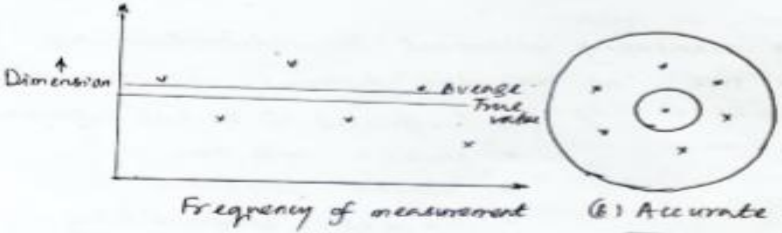
- It refers to the repeat measurement for the same unit of product under identical condition. It indicates to what extent the identically performed measurement agree with each other

- The scatter of these measurement is designated as (= the standard deviation) it is used as an index of precision.

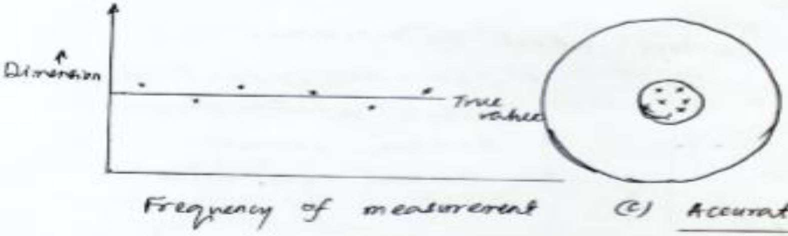
PRECISION AND ACCURACY



(a) Precise but not accurate.



(b) Accurate but not precise.



(c) Accurate and precise.

Fig 1.10: Precision and Accuracy

Spindle Rotational Accuracy

- In Horizontal Machining Centers, HMCs, like in most of other types of machine tools, assembled main spindles units are routinely inspected for its rotational accuracy.

- Run out is the classical method of measuring spindle rotational accuracy. Runout is also called Total Indicator Reading (TIR).

- The mandrel is clamped in machine tool spindle taper bore and the spindle is slowly rotated by hand. The run out measurements on mandrel surface are recorded using precise dial gauges placed on machine table

Failure of cutting tools:

- **Smooth, safe and economic machining necessitate. prevention of premature and catastrophic failure of the cutting tools. reduction of rate of wear of tool to prolong its life To accomplish the aforesaid objectives one should first know why and how the cutting tools fail.**
- **This type of failure also occurs rapidly and are quite detrimental and unwanted. iii) Gradual wear of the cutting tool at its flanks and rake surface**
- **But failure by gradual wear, which is inevitable, cannot be prevented but can be slowed down only to enhance the service life of the tool.**
- **The cutting tool is withdrawn immediately after it fails or, if possible, just before it totally fails.**

Mechanisms and pattern (geometry) of cutting tool wear:

- The rate of such tool wear increases with the increase in temperature at the cutting zone. Diffusion wear becomes predominant when the cutting temperature becomes very high due to high cutting velocity and high strength of the work material.
- The usual pattern or geometry of wear of turning and face milling inserts are typically.
- In addition to ultimate failure of the tool, the following effects are also caused by the growing tool-wear increase in cutting forces and power consumption mainly due to the principal flank wear, increase in dimensional deviation and surface roughness mainly due to wear of the tool-tips and auxiliary flank wear (Vs) , odd sound and vibration worsening surface integrity , mechanically weakening of the tool tip.

Cutting tool wear:

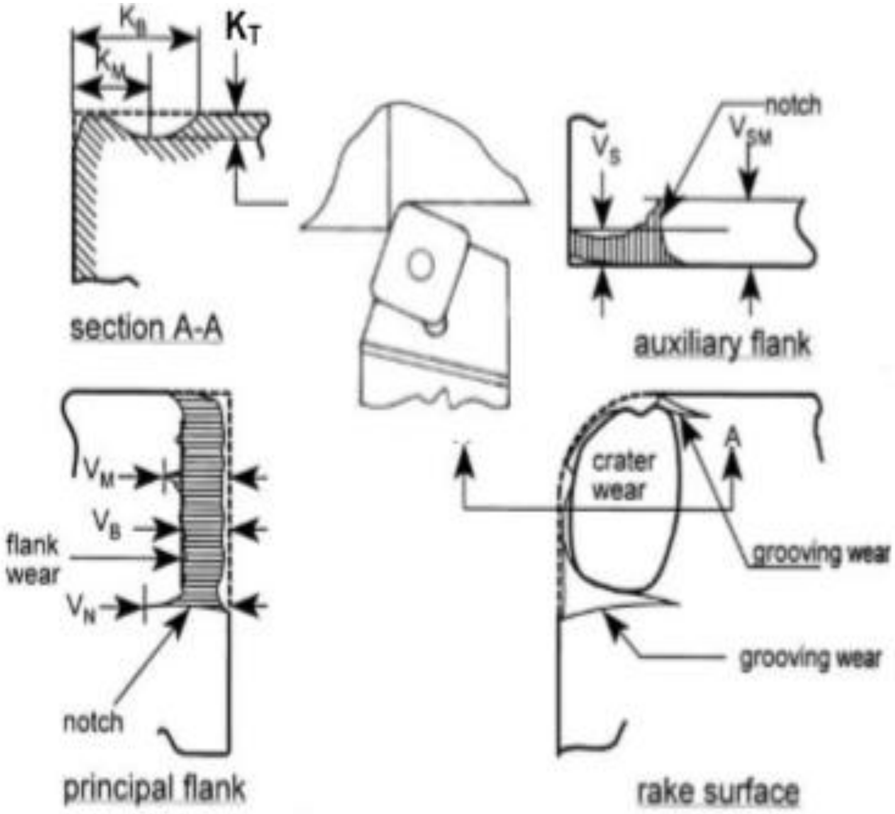


Fig. 3.2.1 (a) *Geometry and major features of wear of turning tools*

PROPERTIES FOR CUTTING TOOL MATERIALS

- **The cutting tools need to be capable to meet the growing demands for higher productivity and economy as well as to machine the exotic materials which are coming up with the rapid progress in science and technology**

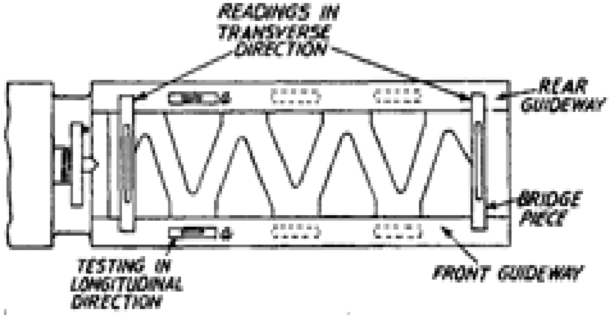
- **high mechanical strength; compressive, tensile, and TRA**
- **fracture toughness – high or at least adequate**
- **high hardness for abrasion resistance**
- **high hot hardness to resist plastic deformation and reduce wear rate at elevated temperature**
- **high heat resistance and stiffness**
- **manufacturability, availability and low cost.**

Taylor’s tool life equation.

- **Wear and hence tool life of any tool for any work material is governed mainly by the level of the machining parameters i.e., cutting velocity, (VC), feed, (so) and depth of cut (t). Cutting velocity affects maximum and depth of cut minimum Variable-stroke piston pump**
- **Taylor derived the simple equation as VTn = C where, n is called, Taylor’s tool life exponent. The values of both ‘n’ and ‘c’ depend mainly upon the tool-work materials and the cutting environment (cutting fluid application).**
- **The value of C depends also on the limiting value of VB undertaken (i.e., 0.3 mm, 0.4 mm, 0.6 mm etc.)**

Alignment tests

- **Before the various tests on any machine tool are carried out, it is very essential that it should be installed in truly horizontal and vertical planes. In horizontal plane, both longitudinal and transverse directions are equally important.**
- **It may be noted that the two guide ways may be perfectly leveled in longitudinal direction, but might not be parallel to each other. This is revealed by the test in transverse direction**

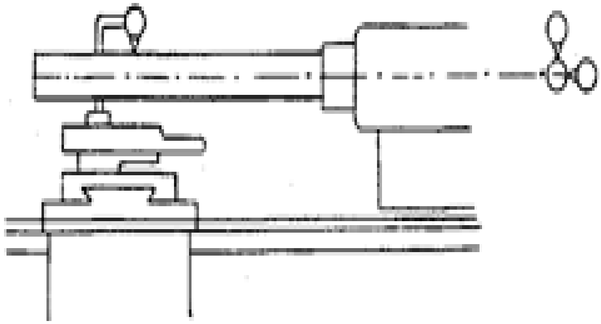


Parallelism of tailstock sleeve to saddle movement:

- **If the tailstock sleeve is not parallel to the saddle movement, the height of dead centre would vary as varying lengths of sleeve are taken out.**
- **The test is carried out by fixing the dial indicator on the tool post and pressing the plunger against the sleeves first in vertical and then in horizontal plane .**
- **The carriage is moved along the full length of the sleeve and deviations as indicated by dial indicator are noted down.**
- **Tailstock sleeve should be rising towards the free end in vertical plane and should be inclined towards the tool pressure in horizontal plane.**

Parallelism of tailstock sleeve taper socket to saddle movement:

- **A mandrel is put in the sleeve socket. The dial gauge is fixed on the tool post and plunger is pressed against the mandreland saddle is moved from one side to the other. This test is carried out in both the horizontal and vertical planes.**
- **This test is to be carried out in vertical plane only. A mandrel is fitted between the two centres and dial gauge on the carriage**



STRAIGHTNESS

- **The straight line represents the path of all linear dimensions. Considering the premise that the shortest distance between two points is along a straight line.**
- **As an introduction to the discussion of straightness measurements, a survey of a few basic methods is made.**
- **concept of linear measurements, is also a functionally important condition of many engineering products.**
- **A physical sense on the part being measured for size, but it must be incorporated in the length measuring instrument.**

TESTS ON MACHINE-TOOL ELEMENTS FOR ACCURACY

- **The object of these tests is to determine whether the various parts or elements of machine-tools have been made accurately and so fit and work together as to produce satisfactory results in the operation of the machines.**
- **Therefore, since the general accuracy of a machine-tool is dependent absolutely upon the accuracy of its component parts or elements, it follows that this latter accuracy is the one to be considered.**
- **The other is strictly a quantitative test, and as such is far more valuable and useful than the former not exclusively, used in connection with the testing of machine-tool parts which are in course of construction.**

Spirit Levels

- **One method of performing this test—and the usual one—involves the employment of a spirit level. The essential feature of a spirit level is a hermetically sealed glass vial of circular section and a more or less curved.**
- **In ordinary practice this curvature ^ which is practically of a circular character — can be imparted to the internal surface of the vial in either of two ways, that is, either by bending the tube from which the vial is made, or by grinding the vial internally so as to make it barrel shaped therein interior.**
- **The vial is fixed in a frame—being firmly embedded in special cement or plaster.**

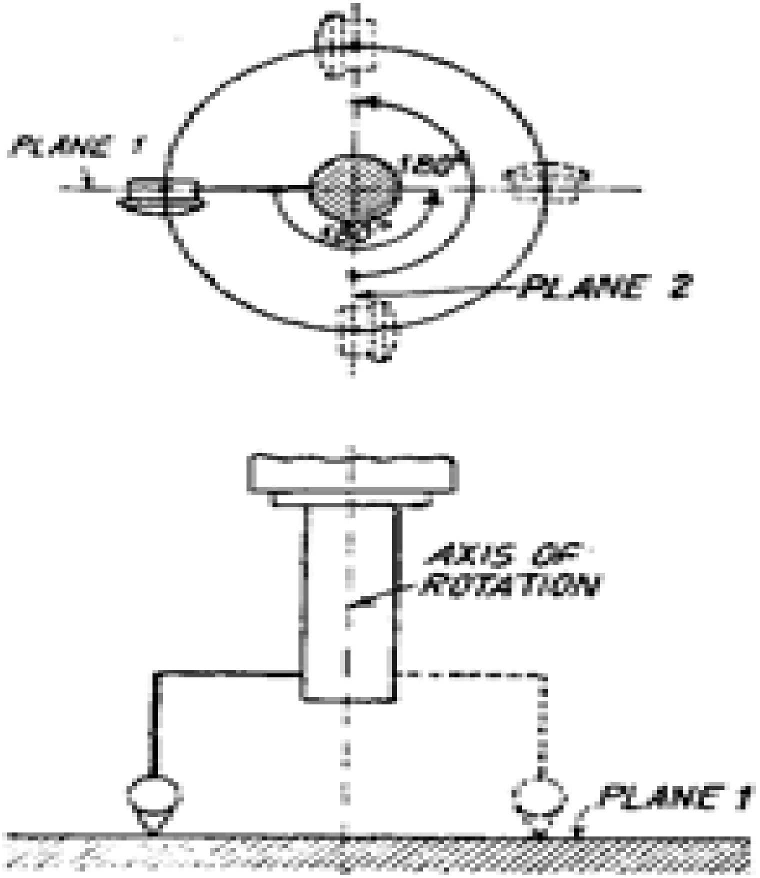
Hydrostatic Level:

- **In this form of levelling instrument the fact that water always tends to find its own level is made use of. It consists essentially of two exactly similar graduated cylinders with a flexible connecting tube between them.**
- **The two sets of cylinder graduations should be exactly alike and related in exactly the same way to the bases of the cylinders; otherwise the instrument is practically worthless.**
- **With this instrument the difference in level between the two points or places tested equals the difference between the heights of water in the two cylinders, the higher cylinder showing the lower head of water.**

SQUARENESS

- **For this test the dial indicator is mounted on an arm which is attached to the spindle representing the axis of rotation.**
- **The plunger of the dial indicator is adjusted parallel to the axis of rotation and made to touch the plane. As the spindle revolves, the dial gauge (or the end of plunger if revolving freely into air) describes a circumstances, the plane of which is perpendicular to the axis of rotation.**
- **The effect of periodical axial slip of the spindle can be eliminated by repeating the above test after moving the dial gauge through 180° relative to the spindle and average of two sets taken.**

SQUARENESS

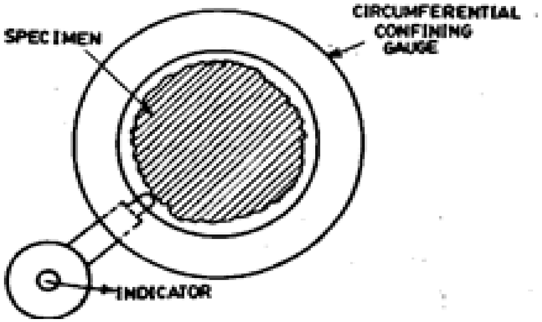


CIRCULARITY

- **In the assembly of circular parts, only the dimensional tolerances on diameter will not suffice the requirements, but it is the geometrical accuracy (accuracy of form) that needs closer attention. If cylindrical parts are measured from devices having diametrically opposite contacts such as micrometer etc.,**
- **Thus the method of circularity measurement has to be such which detects the various possible errors of circularity and this is always done by rotating a part and not measuring static diameter alone.**

Circumferential Confining Gauge.

- It is useful for inspection of roundness in production. However, this method requires a separate highly accurate master for each size part to be measured. The clearance between part and gauge is critical to reliability
- This technique does not allow for the measurement of other related geometric characteristics, such as concentricity, flatness of shoulders, etc. The values obtained are dependent on the shape of the specimen.



UNIT – II

INFLUENCE OF STATIC STIFENESS, THERMAL EFFECTS

In-process measurement of position of processing point

- The common design strategy for machine tool structures can therefore be summed up as:
- 1. Design for bending stiffness,
- 2. Designing for torsional stiffness, and
- 3. Checking dimensions for sufficient strength due to bending and torsion.

  . The structural member is to be designed with respect to stiffness for which shape is the criterion. From the viewpoint of strength the member may then be over dimensioned. Several members in machine tools fall in this group i.e. bed, column etc. for those parts which are designed on the basis of stiffness, the dynamic behavior is of special importance i.e. chatter in cutting machine tools.
- 2. The structural member is to be designed with respect to strength. Deformations must remain within allowable limits.

Factors Affecting Stiffness of Machine Tool Structure and Method Improve It :

- In order to support the work piece and position it correctly with respect to the cutter under the influence of cutting forces it is necessary for the structure to have high static and dynamic stiffness values. Such measurements of nanometre accuracy have often been performed using high-accuracy measuring instruments on a vibration-isolated table in an air-conditioned room.
- Stiffness of the structure is related to its shape of crosssection, cuts and apertures in walls of structures coverplates, arrangement of ribs internally as well as externally etc.
- Whilst a knowledge of the relations of the nodes would lead to a more accurate construction of the deformed shape this is usually unnecessary.

Effect of aperture on torsional stiffness

- In the most of the cases machine tools structures cannot be made of complete closed box type profile. There must be apertures, openings for free flow of chips and other purposes
- The effect of aperture on the torsional stiffness of a box-type structure. It can be seen that a circular hole of diameter d affects a length of approximately twice the diameter, i.e. affected length ,P=2Q. An elongated aperture affects the stiffness even more.
- For symmetrically placed apertures, the effects can be taken into account by multiplying the torsional stiffness with a reduction coefficient.
- In a machine tool higher production rate together with good machining accuracy and surface finish can be achieved by aiming at a structural design that ensures a large stiffness to weight ratio.

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- Only limitation being there load carrying capacity in view of increased danger to warping and buckling. This problem, however, alleviated to a large extent by the use of suitable ribbing designs.
- The stiffness of structures can be improved by using ribs and stiffeners. However, it should be noted that the effect of the ribs and stiffeners depends to a large extent upon how they are arranged.
- **Effect of End Cover plate on stiffness of structure**
- Provision of an end cover plate reduces considerably, the deflections in y and z directions of a thin walled column in torsion Fig. 3.4, while in case of bending no significant improvement is observed.

Contd..

The behavior of column with varying thickness of end cover plate. It can be observed that thickness of end cover plate equal to the wall thickness is giving reasonably good result compare to thicker end cover plates.

- **Effect of ribs arrangement in closed box structure**
- **For the purpose of direct comparison, different ribbing arrangement in case of closed box structure. It is evident from Table 3.7 that only stiffeners used as shown in arrangements 5 and 6 provide significant improvement in the bending and torsional stiffness of box-type structures**

Effect of Vertical Stiffeners

- The columns having internal and external vertical stiffeners, which have been analyzed. Each side of stiffener cross section is kept equal to wallthickness of the column. In both cases, vertical internal and external stiffeners, depth of the stiffeners, denoted by ‘a’, is varied in order to analyze effect on performance.
- **Effect of Horizontal stiffeners**

The positions of internal and external horizontal stiffeners. Depth ‘a’ of stiffeners is varied in steps, which also shows results of combination of horizontal and vertical stiffeners, to analyze its effect on performance of structure.

- . But under bending loads these stiffeners are less effective. Columns having internal horizontal stiffeners are stiffer than those having external horizontal stiffeners. As earlier said, these stiffeners have very high torsional rigidity, while under bending loads they are less effective.

Improving Stiffness of Open Structures

- The stiffness of open structures, such as lathe beds where two plates of structures, top and bottom, connected by ribs, also get affected by arrangement of ribs. The torsional rigidity of open structures has been compared under different stiffener arrangements and the results
- The results of table indicate that only arrangements 4 and 5 are effective in terms of stiffness-to-weight ratio of the structure. Arrangements 4 consisting of two parallel shears, which are connected by diagonal ribs, is commonly used in machine tool beds.
- Finally, stiffness to weight ratio is important factor in deciding the ribbing arrangements. Higher values of stiffness to weight ratio is desirable.

The significance of joints and their orientation upon the overall stiffness of structure:

- It is well established that one of the great obstacles to a complete understanding of the static and dynamic behavior of machine tool structure is the inability to take the effects of the joints fully into account.
- Contribution of various parts of structure in overall flexibility of machine tool, and actual machine tool behavior, as a whole, differs. This is because during analysis of individual structural elements, joint properties of machine tool are not specified.

- Because resultant force will transfer from one part to another through contact area, which is nothing but a joint, either “fixed” or “sliding”.

Evaluation of Machine Tool Structure

- **The analysis of static rigidity and dynamic characteristics of machine tool structures is one of the most important factors in designing high-precision and high efficiency machines.**
- **In order to evaluate operational efficiency and accuracy of machine tools at the design stage, and finally to optimize the machine structures with respect to the performance, structural analysis using computer programming/software must be conducted.**
- **However, the results of research together with the experience of the user form the basis for the design procedures currently available**

Static analysis of machine tool structure.

- **Forces of an essentially static nature result from the static component of the cutting force, the weight of the various machine elements and thermal stresses. The latter source of stressing is not considered here although the methods to be discussed are adaptable to the thermal problem.**

- **Although the changing distribution of the gravity force, due to the movement of the machine carriages and the variable magnitude and direction of the cutting force add to the complexity of the problem this is by far outweighed by simplifications arising from the linear behavior of the stressed structure.**

Wear of cutting tools

- Failure of cutting tools: Smooth, safe and economic machining necessitate prevention of premature and catastrophic failure of the cutting tools • reduction of rate of wear of tool to prolong its life To accomplish the aforesaid objectives one should first know why and how the cutting tools fail.
- If the tip radius of the stylus is sufficiently small, however, the maximum pressure at the contact point will be large enough to cause plastic deformation in soft materials such as aluminum.

- machining necessitate prevention of premature and catastrophic failure of the cutting tools • reduction of rate of wear of tool to prolong its life To accomplish the aforesaid objectives one should first know why and how the cutting tools fail.

Errors due to variation of cutting force

- A body supported by bearings, behaves as if all the bearings are concentrated at the center of stiffness

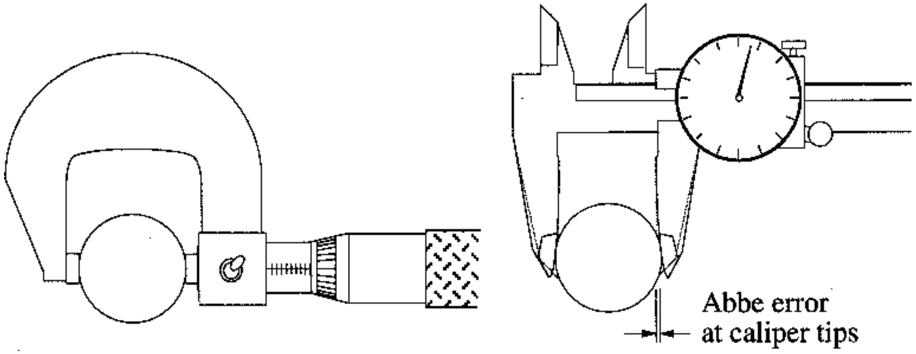
The point at which when a force is applied to a locked-in-place axis, no angular motion of the structure occurs

It is also the point about which angular motion occurs when forces are applied elsewhere on the bodyFound using a center-of-mass type of calculation

- Errors act through the There are MANY types of errors that can affect machine accuracy
- Abbe (Sine) Errors
- Cosine Errors
- Linear Motion Axis Errors
- Rotary Motion Axis Errors
- Rolling Element Motion Errors
- Surface Finish Effect Errors

Errors due to variation of cutting force

- ➢Kinematic Errors
- ➢Load Induced Errors
- ➢Thermal Growth Errors
- ➢Abbe(sine) Errors
- ➢Thermal: Temperatures are harder to measure further from the source



- ➢Geometric: Angular errors are amplified by the distance from the source

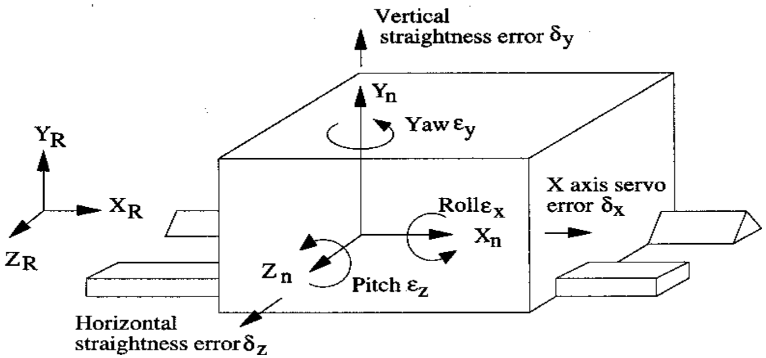
Cosine Errors

- Thinking of Abbe errors, and the system FRs is a powerful catalyst to help develop DPs, where location of motion axes is depicted schematically

Cosine Errors

Cosine errors have much less effect than Abbe errors, but they are still important, particularly in large systems

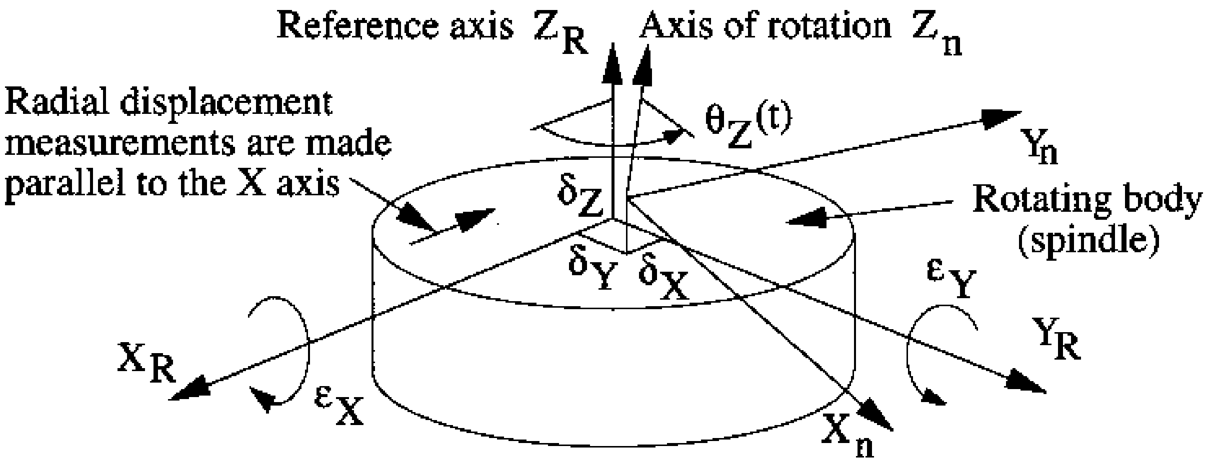
Linear Motion Axis Errors



Every linear motion axis has one large degree of freedom, and five small error motions

Rotary motion Axis Error

Every rotary motion axis has one large degree of freedom, and five small error motions



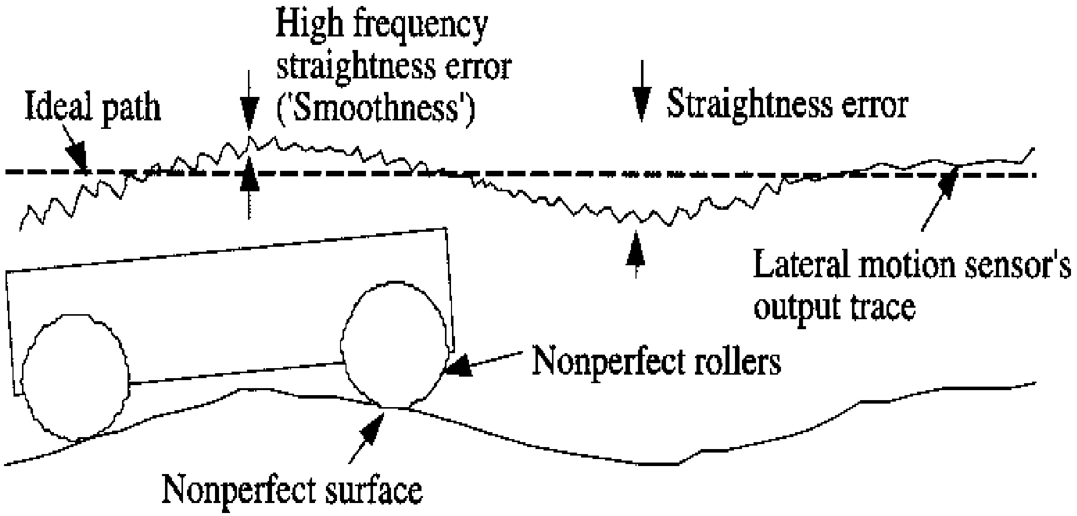
Rolling Element Motion Errors:

Rolling element bearings average out surface finish errors by their numbers

-Separators can reduce error (noise) by a factor of 5 or more

Feed unit for sample and horizontal resolution

Rolling element bearings are still subject to form errors in the surface

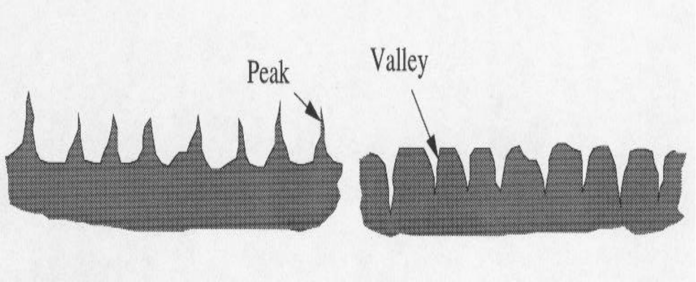


Surface Finish Effect Errors

- **Surfaces with sharp peaks wear quickly (positive skewness)**

- **Surfaces with valleys wear slowly**

- **Both surfaces below have equal average roughness (Ra values)**



- **Sliding contact bearings tend to average out surface finish errors and wear less when the skewness is negative**

Thermal Growth Errors

- Very troublesome because they are always changing

- Very troublesome because components' heat transfer coefficients vary from machine to machine

- Design strategies to minimize effects:
  - Isolate heat sources and temperature control the system
  - Maximize conductivity, OR insulate
  - Combine one of above with mapping and real time error correction
- May be difficult for thermal errors because of changing boundary conditions.

- Combine two of the above with a metrology frame

Contd..

- **Conduction**
  - **Use thermal breaks (insulators)**
  - **Keep the temperature the same in the building all year**
  - **Convection**
  - **Use sheet metal or plastic cowlings**

- **Radiation:**

  Plastic PVC curtains (used in supermarkets too!) are very effective at blocking infrared radiation

  Use indirect lighting outside the curtains, & never turn the lights off

UNIT-III

PRECISION MACHINING

INTRODUCTION TO PRECISION MACHINING

Nanotechnology has been steadily receiving significant attention during the past decades both in scientific and engineering communities as well as in popular media. Nanometer-scale materials or nanomaterials often have distinctly different physical and chemical properties in comparison to their bulk form. Indeed several size-dependant phenomena makes nanomaterials attractive in terms of potential applicability compared to their bulk form, justifying the importance and attention such research is receiving.

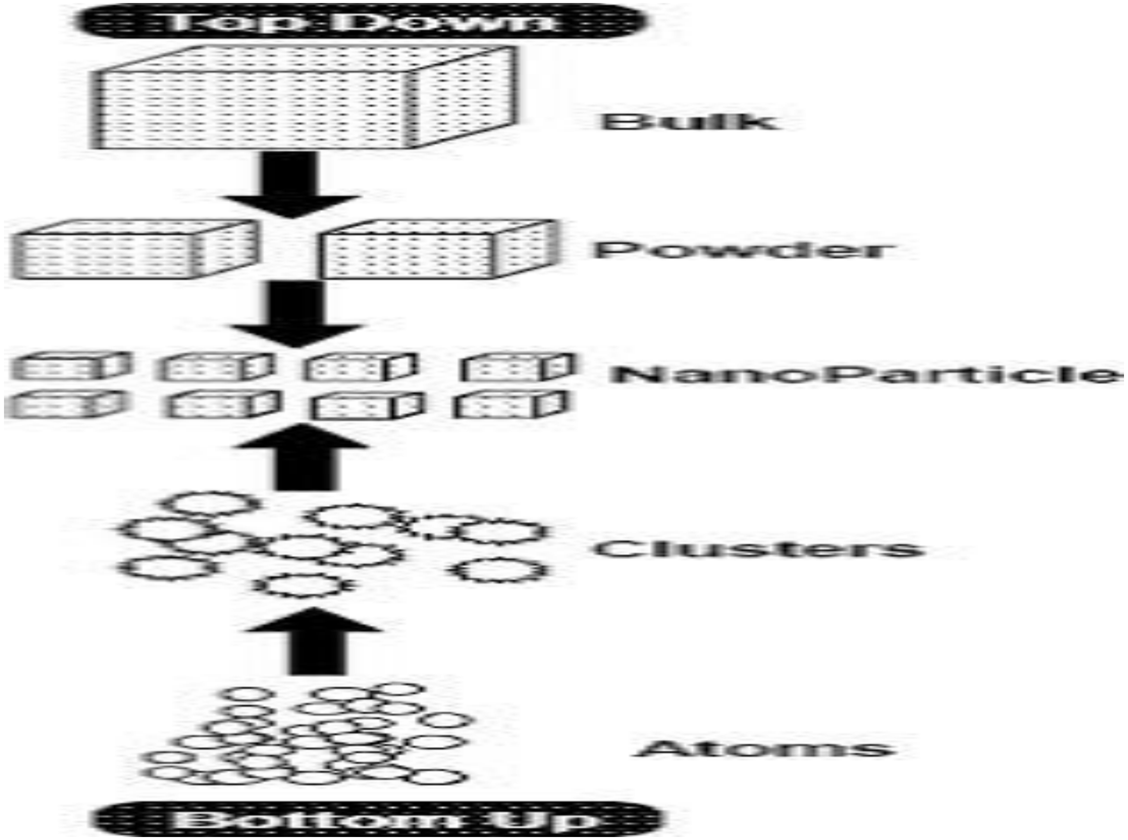
Overview Of The Two Methods

Top-Down Method:

1. *Mechanicanosynthetic Methods :-* Mechanical methods offer the least expensive ways to produce nanomaterials in bulk. Ball milling is perhaps the simplest of them all. Ball milling produces nanomaterials by mechanical attrition in which kinetic energy from a grinding medium is transferred to a material undergoing reduction.

2. *Compaction and consolidation* is an industrial scale process wherein nanomaterials are "put back together" to form materials with enhanced properties. Metallic alloys can be made this way. Many top-down mechanical methods are utilized by industry.

Overview Of The Two Methods



Overview Of The Two Methods

Bottom-Up Method:

Bottom-up methods start with atoms or molecules to form nanomaterials. *Chemical vapor deposition* is a gas-phase process by which reactive constituents react over a catalyst or pre-templated surface to form nanostructure materials. The economical synthesis of carbon nanotubes is by CVD. Precursors in the form of methane or acetylene or other carbon source gases are passed over Co, Fe or Ni catalyst.

Once decomposed into carbon, nanotubes are formed by the catalyst particle. *Atomic layer deposition* is an industrial process that is capable of coating any material, regardless of size, with a monolayer or more of a thin film. *Molecular beam epitaxy* and *MOCVD* are other industrialized processes that are considered to be bottom-up.

Methods to Synthesis of Nanomaterials:

In general, top-down and bottom-up are the two main approaches for nanomaterials synthesis.

a. Top-down: size reduction from bulk materials.

b. Bottom-up: material synthesis from atomic level.

Top-down routes are included in the typical solid –state processing of the materials. This route is based with the bulk material and makes it smaller, thus breaking up larger particles by the use of physical processes like crushing, milling or grinding. Usually this route is not suitable for preparing uniformly shaped materials, and it is very difficult to realize very small particles even with high energy consumption. The biggest problem with top-down approach is the imperfection of the surface structure.

Methods to Synthesis of Nanomaterials:

Such imperfection would have a significant impact on physical properties and surface chemistry of nanostructures and nanomaterials. It is well known that the conventional top-down technique can cause significant crystallographic damage to the processed patterns

Bottom –up approach refers to the build-up of a material from the bottom: atom-by-atom, molecule-by-molecule or cluster-by-cluster. This route is more often used for preparing most of the nano-scale materials with the ability to generate a uniform size, shape and distribution. It effectively covers chemical synthesis and precisely controlled the reaction to inhibit further particle growth. Although the bottom-up approach is nothing new, it plays an important role in the fabrication and processing of nanostructures and nanomaterials.

Evolution of Nanotechnology in India

The scale of nanotechnology's operation has raised concerns over nanotechnology risk and safety aspects with respect to environment and health safety (EHS) as well as its ethical, legal and social implications (ELSI). The World over, countries are vying to establish a regulatory framework to address these concerns. The initiatives in this regard comprise enacting new regulations or amending existing regulations/laws for nanotechnology; enforcing safety guidelines for researchers/workers in the laboratories in universities/research centres or companies; and establishing a global standard.

Evolution of Nanotechnology in India

However, the thrust came with the launch of “Programme on Nanomaterials: Science and Devices” in 2000 by the Department of Science and Technology (DST). DST launched special initiative to generate and support some end-to-end projects leading to tangible processes, products and technologies after realizing the importance of nanomaterials and their far-reaching impact on technology (DST 2001). In 2001-2002, the DST set up an Expert Group on “Nanomaterials: Science and Devices”. The Government identified the need to initiate a Nanomaterials Science and Technology Mission (NSTM) in the 10th Five Year Plan (2002-07) after taking into consideration the developments in nanotechnology.

Applications of Nanotechnology with Examples

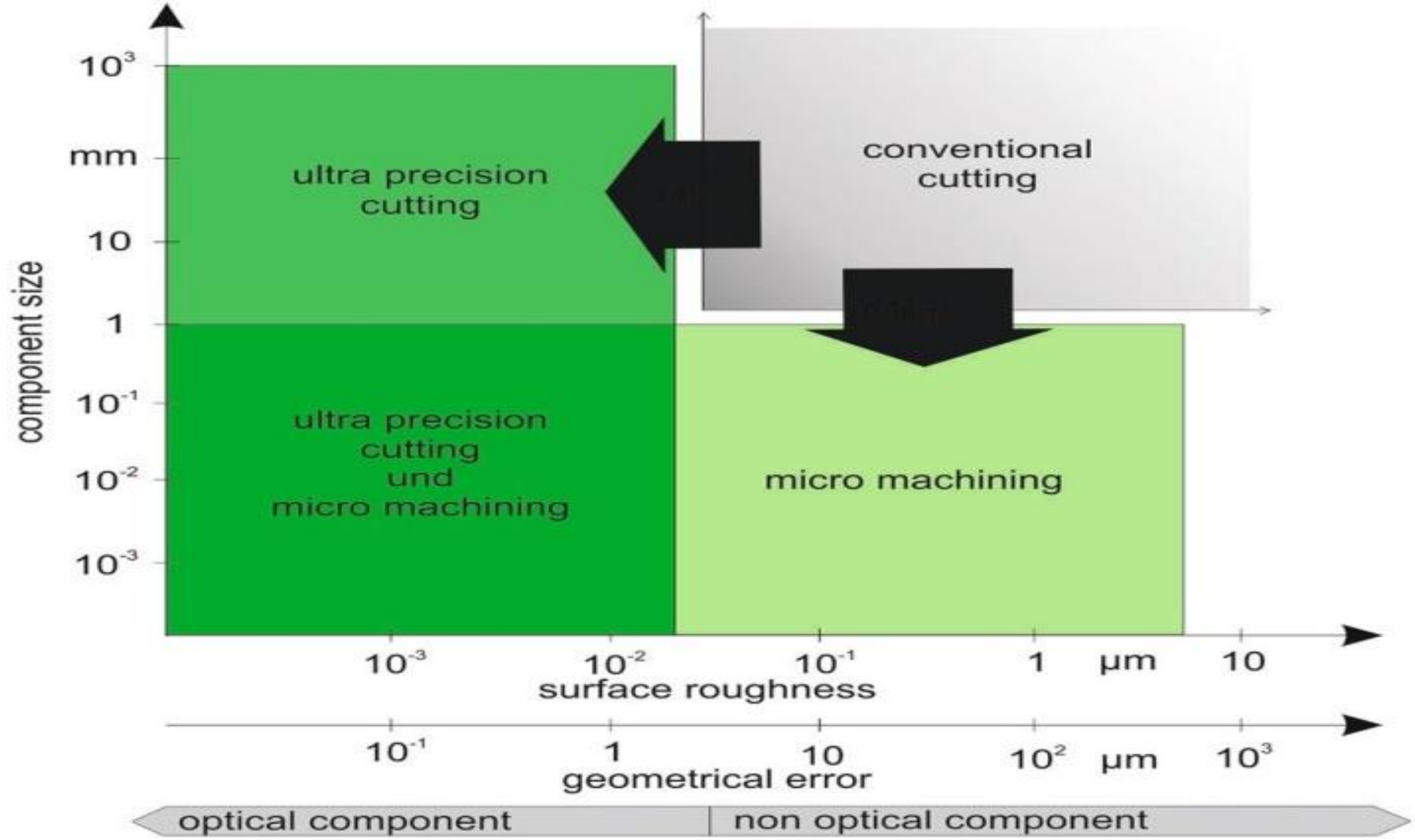
Accordingly, on 3 May 2007, a Mission on Nano Science and Technology (Nano Mission) was launched by the DST to foster, promote and develop all aspects of nanoscience and nanotechnology which have the potential to benefit the country. The Mission is steered by a Nano Mission Council (NMC) under the Chairmanship of Prof. CNR Rao. The primary objectives of the Nano-Mission are:

- Infrastructure Development for Nano Science and Technology Research
- Public Private Partnerships and Nano Applications and Technology Development
- Human Resource Development
- International Collaborations
- Academia-Industry partnerships to be nurtured under these programmes

Precision and Micro Machining:

Ultra precision and micro manufacturing are playing a significant role in advanced manufacturing technology. The applications of ultra precision cutting and micro machining are increasing in the last decades and keep fueling market economy. Ultra precision processes allow to achieve surface roughness down to the nanometer scale and are applied for example to manufacture optical components. Micro machining processes on the other hand are adequate technologies to manufacture micro components, micro features, and micro structures.

Precision and Micro Machining:

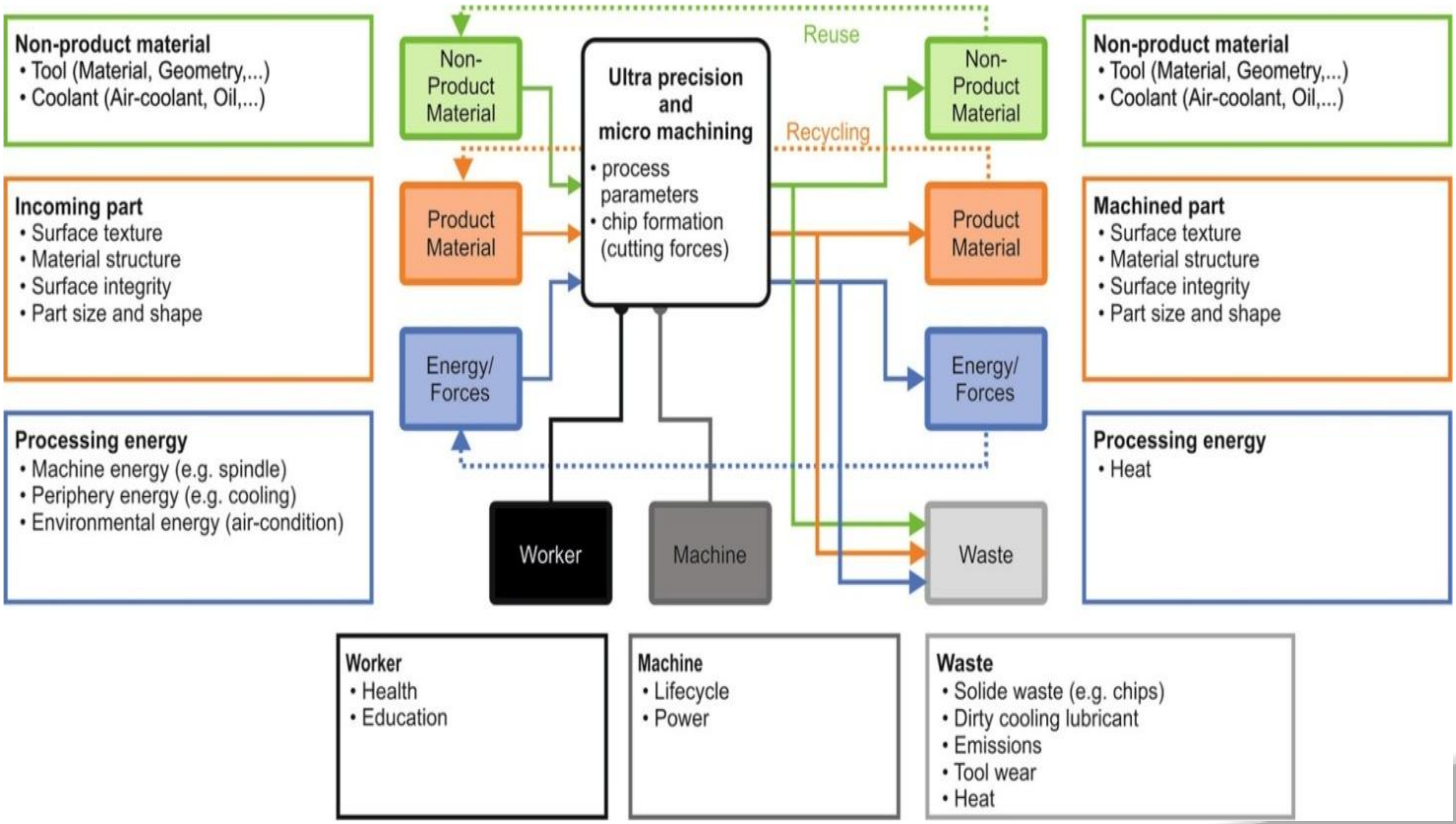


Component size and accuracy in micro machining and ultra precision cutting

Precision and Micro Machining:

For example: composite materials have been increasingly used in aerospace industry, satellite bearing, inertia navigation systems, and laser reflectors. Ultra precision manufacturing not only lowers the cost of optical parts themselves but also for mold cavities of mass production lenses. For example, the production cost of contact lenses both soft and hard can be reduced by manufacturing mold cavities in an ultra precision machining process compared to polishing processes.

Sustainability Aspects in Ultra Precision and Micro Machining



Non-product material
- Tool (Material, Geometry,...)
- Coolant (Air-coolant, Oil,...)

Incoming part
- Surface texture
- Material structure
- Surface integrity
- Part size and shape

Processing energy
- Machine energy (e.g. spindle)
- Periphery energy (e.g. cooling)
- Environmental energy (air-condition)

Non-Product Material

Product Material

Energy/ Forces

Ultra precision and micro machining
- process parameters
- chip formation (cutting forces)

Reuse

Recycling

Non-Product Material

Product Material

Energy/ Forces

Worker

Machine

Waste

Non-product material
- Tool (Material, Geometry,...)
- Coolant (Air-coolant, Oil,...)

Machined part
- Surface texture
- Material structure
- Surface integrity
- Part size and shape

Processing energy
- Heat

Worker
- Health
- Education

Machine
- Lifecycle
- Power

Waste
- Solide waste (e.g. chips)
- Dirty cooling lubricant
- Emissions
- Tool wear
- Heat

In- and output diagram of ultra precision and micro machining

Diamond Turning of Parts to Nanometer Accuracy

The use of special machine tools with single-crystal diamond-cutting tools to produce metal optics is called diamond turning. The manufacture of optical surfaces by diamond turning is relatively new compared to the traditional optical-polishing methods. In terms of geometry and motions required, the diamond-turning process is much like the step of "generating the optical surface" in traditional optical fabrication. However, the diamond- turning machine is a more sophisticated piece of equipment that produces the final surface, which typically does not need the traditional polishing operation. But surface quality produced by the "best" diamond turning does not yet match the best conventional- polishing practice. Yet , the limits of diamond turning for both figure and surface finish accuracy have not yet been reached

Diamond Turning of Parts to Nanometer Accuracy

The Advantages Of Diamond Turning

The advantages of diamond turning over the more traditional optical fabrication technique of lapping and polishing

1. **It can produce good optical surfaces clear to the edge of the optical element. This is important, for example, in making scanners, polygons, special shaped flats, and when producing parts with interrupted cuts.**
2. **It can turn soft ductile materials that are extremely difficult to polish. It can easily produce of f-axis parabolas and other difficult-to-lap spherical shapes.**
3. **It can produce optical elements with a significant cost advantage over conventional lapping and polishing where the relationship of the mounting surface—or other feature—to the optical surface are very critical . Expressed differently, this feature of diamond turning offers the opportunity to eliminate alignment in some systems.**

Diamond Turning of Parts to Nanometer Accuracy

COMPARISON OF DIAMOND TURNING AND TRADITIONAL OPTICAL FABRICATION

In diamond turning , the final shape and surface of the optical produced depends on the machine tool accuracy , whereas , in traditional optical fabrication , the final shape and surface of the optical element are produced by lapping and polishing with an abrasive- loaded lap . The differences between diamond turning and traditional optical fabrication can be summarized by describing diamond turning as a displacement - controlled process versus a force - controlled process for traditional optical fabrication. A traditional polishing machine used for optical fabrication depends on the force being constant over the area where the abrasive-loaded lap—or tool—touches the surface being worked.

BASIC STEPS IN DIAMOND TURNING:

Much like the traditional optical-fabrication process, the diamond-turning process can be described as a series of steps used to make an optical element. The steps used in diamond turning are

Preparing the blank with all the required features of the element with an extra thickness of material (generally 0.1 mm extra material or plating is adequate) on the surface to be diamond turned

1. Mounting the blank in an appropriate fixture or chuck on the diamond-
2. Selecting the diamond tool appropriate for material and shape of optical component
3. Mounting and adjusting the diamond tool on the machine
4. Machining the optical surface to final shape and surface quality
5. Cleaning the optical surface to remove cutting oils or solvents

Machining of micro-sized components

There is a growing demand for industrial products with increased number of functions and of reduced dimensions. Micro-machining is the most basic technology for the production of such miniature parts and components. Micro machining is defined as the ability to produce features with the dimensions from 1 m to 999 m or when the volume of the material removed is at the micro level. Lithography based micro-machining technology.

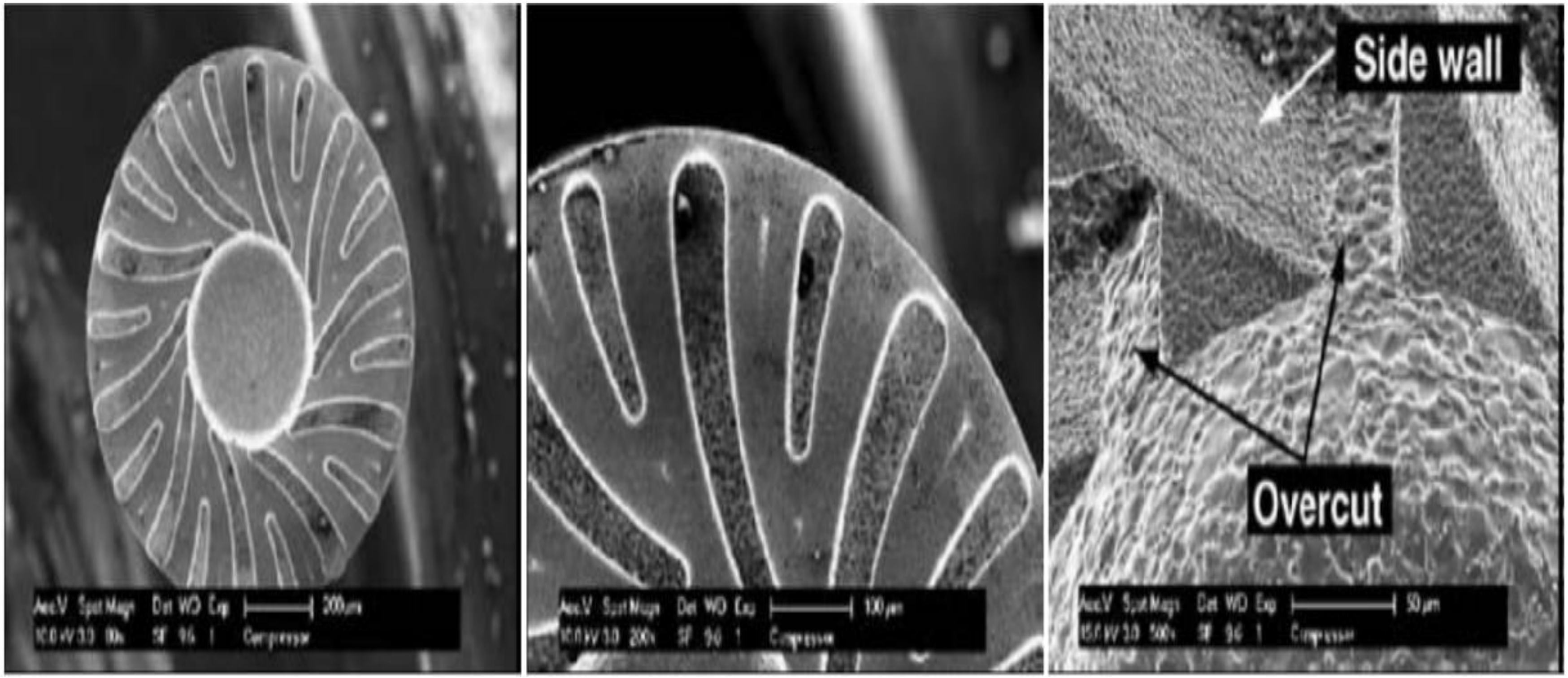
However, these methods, in general, lack the ability of machining three-dimensional shapes because of poor machining control in the Z axis. Fabrication using hard and difficult-to-machine materials such as tool steels, composites, super alloys, ceramics, carbides, heat resistant steels and complex geometries for demanding aerospace, mechanical or biomedical applications requires alternative novel methods.

APPLICATIONS OF MICROMACHINING

Production of Micro-Compressor

It is a two-and-a-half dimensional structure, machined on the tip of a and work-piece are tungsten carbide and stainless steel, 1-mm diameter cylinder. The Materials used for electrode respectively. The centre hole with diameter 0.3 mm is micro-EDM drilled directly with a purchased electrode. The blades are micro-EDM milled with the same tool after it is reduced to a diameter of 40 m by WEDG.

APPLICATIONS OF MICROMACHINING



A micro-compressor on a Ø1 mm cylinder: top and detail views

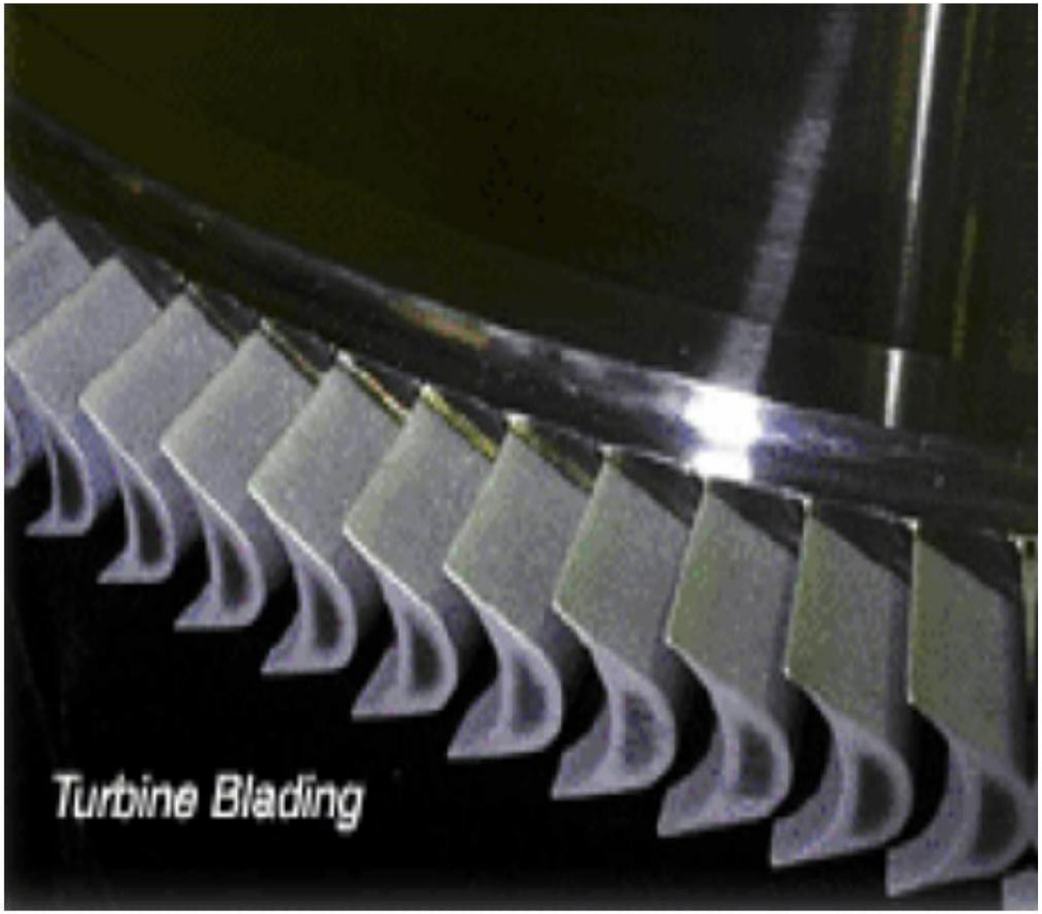
APPLICATIONS OF MICROMACHINING

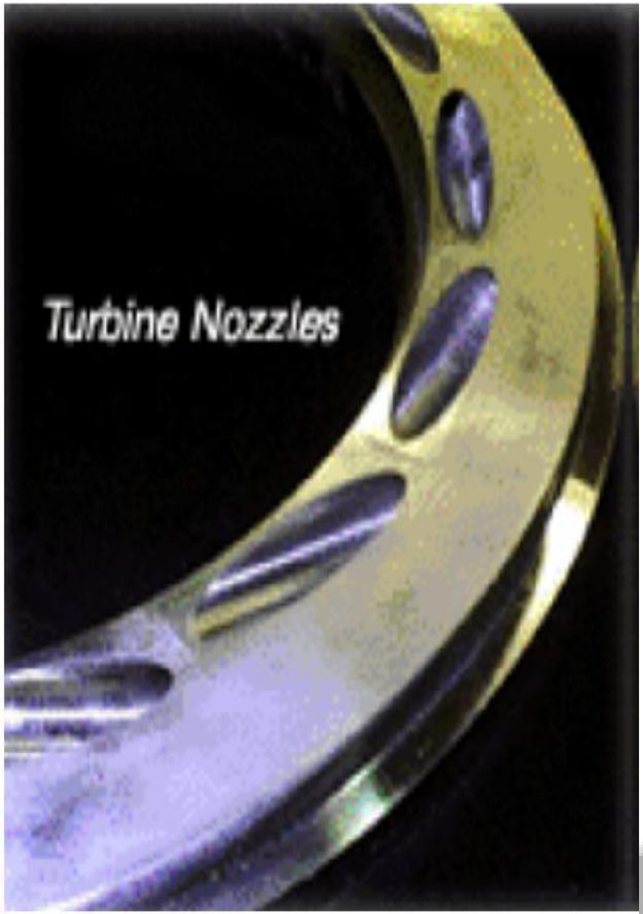
Cooling Holes in Turbine Blades

The main objective of turbine blade cooling is usually to achieve maximum heat transfer coefficients while minimizing the coolant flow rate. Usually the turbine blades are made of a super alloy with a very high melting temperature. By using the lost wax method, these cavities are cast. With this technique, it is possible to produce cavities with a serpentine shape.

The other method employs drilling to provide the blades with cooling holes. These holes are placed in the span wise direction of the turbine blades. In both the cases, the walls of the passage have ribbed surfaces. Although the technique of casting has been improved tremendously over the years, it is still very difficult to develop cavities over large parts.

APPLICATIONS OF MICROMACHINING





MIRROR GRINDING OF CERAMICS

1. As ultra-precision parts made of hard and brittle materials are increasingly used these days, the machining of structural ceramics, electronic ceramics, optical glass and heat treated steel has become an important research area.
2. However, the grinding of these hard and brittle materials using conventional grinding wheels is difficult, with ultra-precision grinding even more difficult. Single point cutting tools which have been used effectively in the cutting of ductile materials cannot be used in the machining of hard and brittle materials. Diamond or CBN (cubic boron nitride) wheels may be used in the grinding of these materials, if submicron precision is not required. Recently, the ultra-precision grinding of these materials has become possible by the development of the cast-iron fiber bonded diamond wheel and the electrolytic in-process dressing (ELID) method.

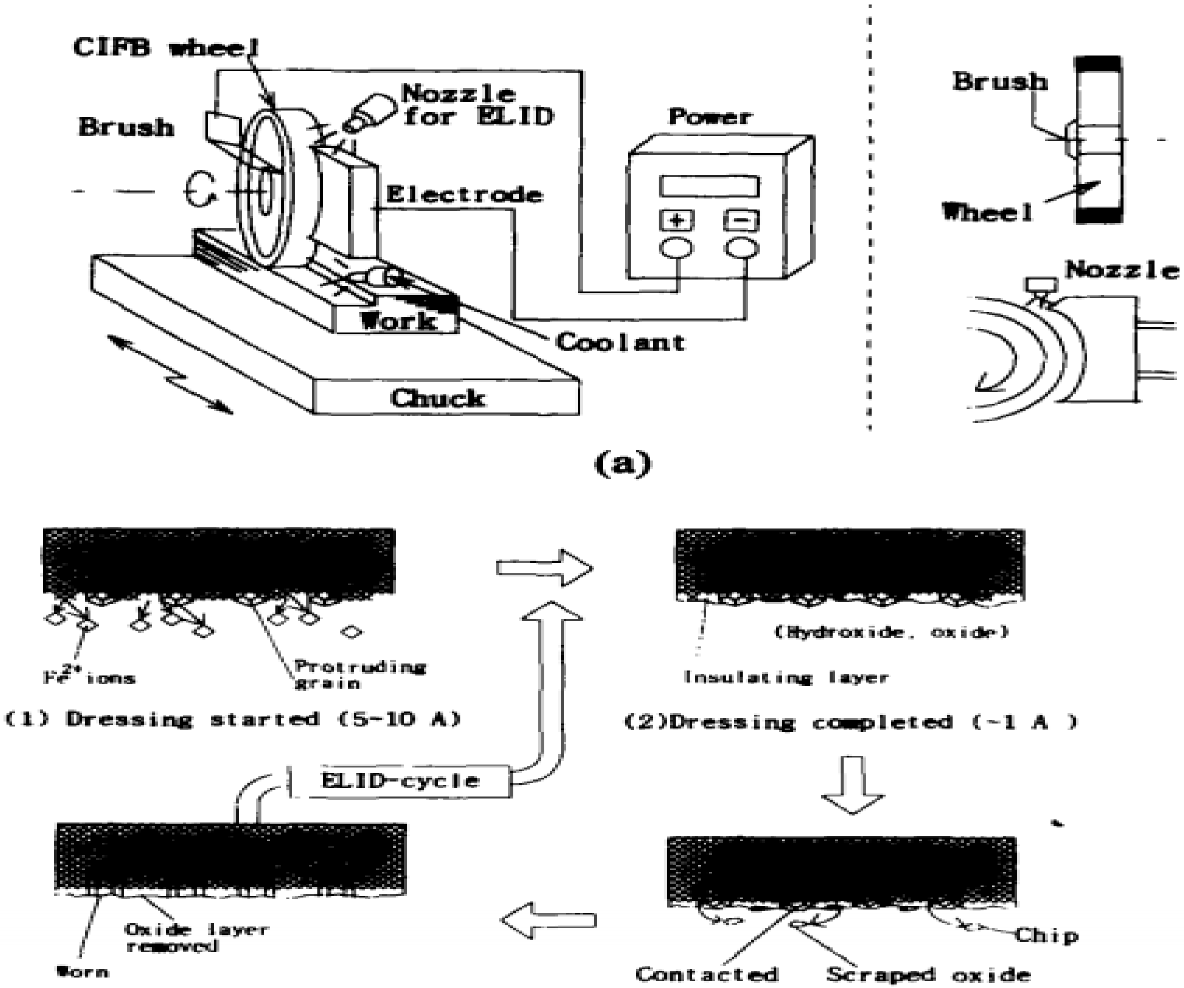
DESIGN OF THE GRINDING MACHINE TOOL:

1. The spindle and the feed mechanism for the ultra-precision machine tool should have high stiffness and low frictional resistance for high rotational accuracy and smooth feed motion. Also, the structural material must have high stiffness and high damping.
2. Since aero-static spindles have been widely used for ultra-precision machine tools owing to theirs rotating accuracy. High rotating speed and low friction, in this study the air spindle chosen has the driving motor inside of its spindle housing was used.
3. The built-in type motor removes the difficulty of assembling the spindle and the driving motor, although there is a tendency of the spindle to increase in temperature. The strokes of the machine tool are 400 mm along the x-axis, 250 mm along the y-axis and 300 mm along the z-axis, respectively.

Dynamic Performance Test of the Grinding Machine :

1. The dynamic characteristics of the spindle and the headstock including the spindle were measured by giving impulse signals and measuring responses . The devices used for the vibration test were the FFT analyzer, impulse hammer, accelerometer and signal amplifier.
2. The schematics of the measuring system for the vibration test. The vibration tests of the main spindle were performed in two cases: one case where the accelerometer was mounted on the spindle housing and the other case where the accelerometer was mounted on the spindle nose.
3. The vibration tests of the two cases gave similar results. When the supplied air pressure was higher than 0.5 MPa, which was much higher than the rotational frequency of the spindle in the working range and then the damping factor of the spindle was 1.1%. spindle.

Dynamic Performance Test of the Grinding Machine :



Basic principle and dressing cycle of the ELID grinding: (a) basic principle; (b) dressing cycle.

ULTRA PRECISION BLOCK GAUGES:

1. **Gauge blocks (also known as gage blocks, Johansson gauges, slip gauges, or Jo blocks) are a system for producing precision lengths. The individual gauge block is a metal or ceramic block that has been precision to a specific thickness. Gauge blocks come in sets of blocks with a range of standard lengths. In use, the blocks are stacked to make up a desired length.**
2. **An important feature of gauge blocks is that they can be joined together with very little dimensional uncertainty. The blocks are joined by a sliding process called *wringing*, which causes their ultra-flat surfaces to cling together. A small number of gauge blocks can be used to create accurate lengths within a wide range. By using 3 blocks from a set of 30 blocks, one may create any of the 1000 lengths from 3.000 to 3.999 mm in 0.001 mm steps (or .3000 to .3999 inches in 0.0001 inch steps).**

ULTRA PRECISION BLOCK GAUGES:

More recent grade designations include (U.S. Federal Specification GGG-G-15C):

- **0.5 — generally equivalent to grade AAA**
- **1 — generally equivalent to grade AA**
- **2 — generally equivalent to grade A+**
- **3 — compromise grade between A and B**

and ANSI/ASME B89.1.9M, which defines both absolute deviations from nominal dimensions and parallelism limits as criteria for grade determination. Generally, grades are equivalent to former U.S. Federal grades as follows:

- **00 — generally equivalent to grade 1 (most exacting flatness and accuracy requirements)**
- **0 — generally equivalent to grade 2**
- **AS-1 — generally equivalent to grade 3 (reportedly stands for American Standard - 1)**
- **AS-2 — generally less accurate than grade 3**

UNIT – IV

NANO-MEASURING SYSTEMS

In-process measurement of position of processing point

- In order to process a work piece to nanometre-order accuracy, measuring and control techniques of nanometre accuracy or better are essential. Nanotechnology must therefore be considered as an integrated technology of processing, measurement, and control.
- This section discusses some advantages, the present potential, and the future of nanometre-order measurement techniques for in-process or in-situ mode. In process measurement will be desirable at the processing point if possible.
- Workpiece referred form accuracy control’ (WORFAC)2 is a simple method to control the relative positioning of workpiece and tool instead of trying to control all the mechanical elements, to increase their individual accuracies, and to improve environmental conditions such as temperature, humidity, and vibration.

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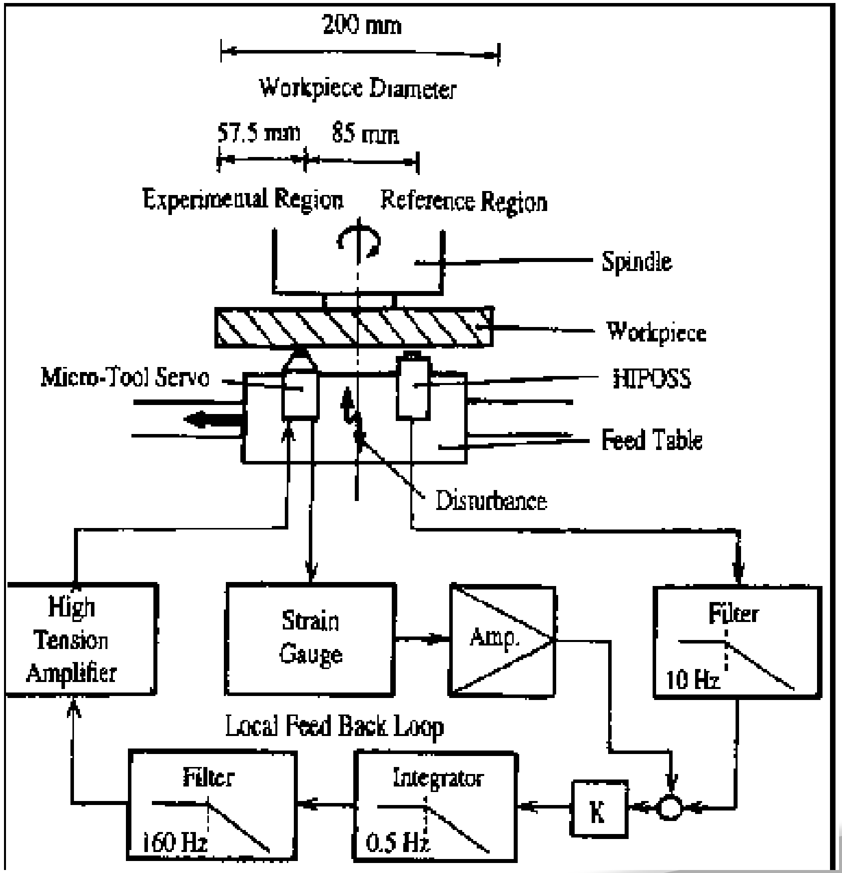
Figure.1 shows schematically an experiment to demonstrate the feasibility of WORFAC.



Post-process and on-machine measurement of dimensional features

- Post-process measurement is the quality testing of a machined workpiece, usually dimensional measurement such as length, outer and/or inner diameter, hole distance, surface roughness, and surface contour.
- Such measurements of nanometre accuracy have often been performed using high-accuracy measuring instruments on a vibration-isolated table in an air-conditioned room.
- On-machine measurement is intermittent or stop- and; measure, in which the measuring instrument is placed on or unified with the machine tool.
- It is important to keep the workpiece held with a chuck during the measurement so as to be able to reprocess immediately if necessary.

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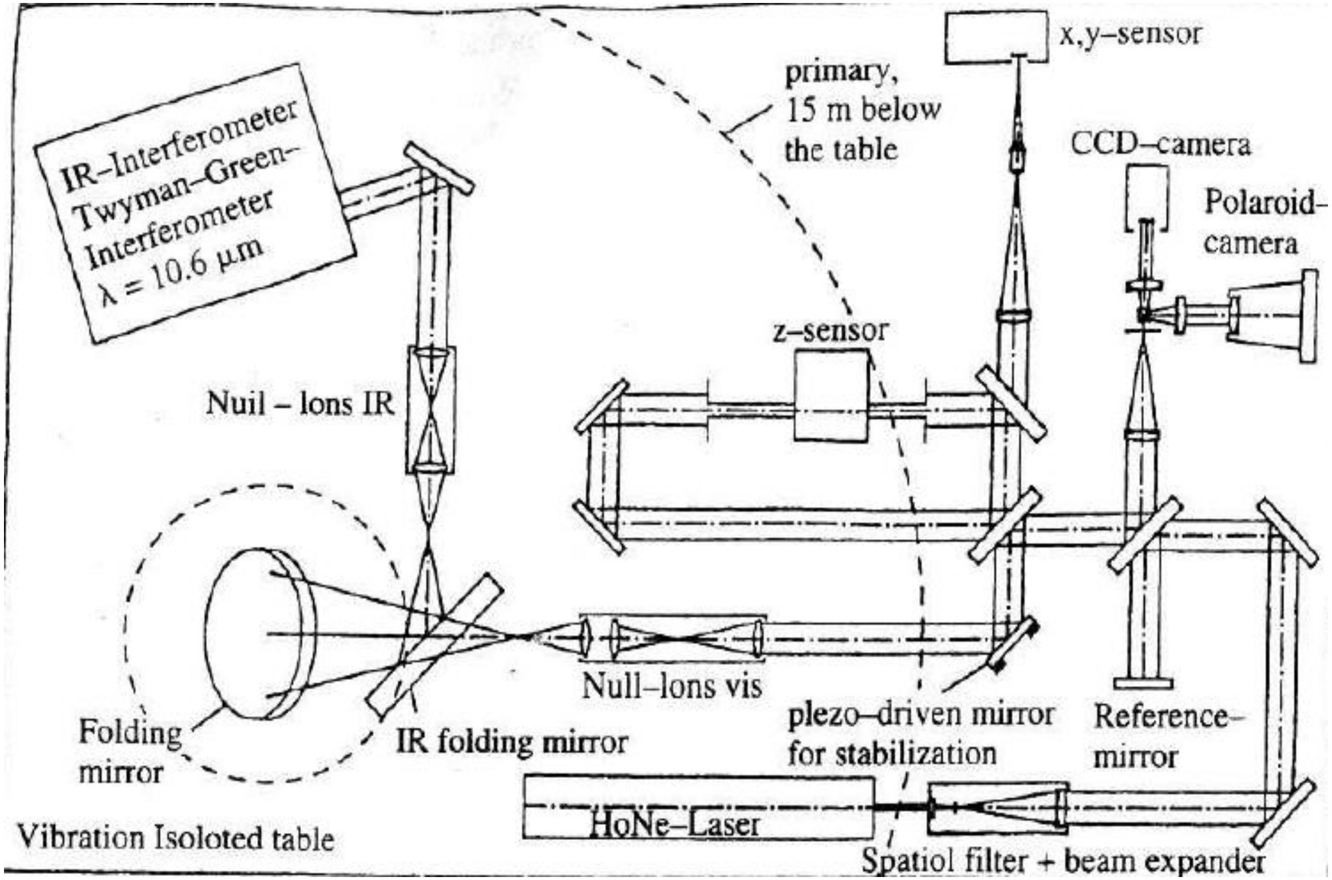

fig. Zeiss system of stabilization of the interferogram for large optics measurement.

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- On-machine measurement has been widely practiced in the manufacture of opitical parts. In thepolishing of relatively small optical parts, Newton interference fringes formed between a test plate and a workpiece surface are sometimes observed to check the residual error in shape.

- Movements of the measuring instrument relative to the mirror and air turbulence are the main problems to be solved in order to perform measurements of nanometre-order accuracy, especially for interferometers with temporal scanning. Figure 4 shows a Zeiss solution to the problem(l).

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- Unlike the well-known interferometers with fringe scanning, in which several interferograms are detected and processed to map a wavefront, the DMI interferometer uses only one interferogram with narrow-spaced fringes to calculate a phase map in real time.

- Digital pipeline processing gives DMI some advantages, e.g. insensitivity to vibrations and ability to average a large number of wavefronts so as to reduce random errors such as errors from air turbulence.

- The CSSP omits the recheking process by adopting a figuring system having both the measurement and polishing units on a single baseplate. Figure 6 shows the measurement system for the Z-coordinate.

Mechanical Measuring Systems

- A mechanical measuring instrument, therefore, consists of a probe, a device to support the probe while converting its motion into an electrical quantity, and a device to analyse the measured results and display the evaluated value.

- A typical instrument is the high- magnification profile instrument, which successively measures the surface profile from the motion of a solid stylus.

- In addition, mechanical displacement measuring instruments and capacitance-type sensors with maximum resolutions < 10 nm are mentioned in the discussion on conversion methods for the mechanical quantity.

Features of mechanical measuring systems

- **Because the mechanical quantity at the measurement point is directly measured in a mechanical measuring system, such a system has the advantages that the measurement procedure is straightforward and the measurement accuracy and resolution can be directly inspected.**
- **Although this deformation is usually an elastic one, plastic deformation can occur in soft metals, resulting in surface damage.**
- **Thus in modem mechanical measuring systems, the change in mechanical quantity at the measurement point is mechanically extracted and then measured by a non-contact measuring system.**

Features of the high-magnification profile instrument

- In profile measurement, a record of the magnified surface profile is obtained by allowing the detector unit which houses the stylus to scan mechanically over the measured surface in one direction to measure the coordinates of consecutive points on the surface profile.
- At the same time, the position of the measured point is measured by the feed distance (i.e. horizontal direction). A high-precision feed device is necessary.
- Since the accuracy (i.e. straightness) of the feeding motion directly affects that of the vertical measurement, while the readout accuracy of the feed distance directly affects the horizontal accuracy.

Vertical resolution of profile instrument

- In electrical magnification, a transducer is used to convert the movement of the stylus into electrical signals, which are then amplified.
- Several countries undertook research in this field, with the result that a vertical resolution of 0.5 nm was achieved in the 1960s, improving 0.1 nm by the mid-1980s and 0.03 nm by the late 1980s.
- It achieved a vertical resolution of ~ 0.1 gm. Research on ways to accomplish magnification by electrical means began in the 1930s, and ever since 1935, when Rank Taylor Hobson Ltd announced the Talysurf Model 1, electrical magnification has become the more usual method.

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- The major requirements for making measurements of ~ 1 nm are discussed below.
- Radius of curvature of stylus tip and measurement force In general, if Fs is the static load or measurement force at the mean position.
- when the stylus and sample surface are in contact, the maximum dynamic measurement force of the stylus continually tracing the surface profile can be approximated(1) by 2Fs. This measurement force causes elastic deformation at the contact point.
- If the tip radius of the stylus is sufficiently small, however, the maximum pressure at the contact point will be large enough to cause plastic deformation in soft materials such as aluminum.

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- For measurements of profile features of < 10 nm, a feedspeed of 2-100 µm s-1 is used; the accuracy of the feed motion achieved in these cases is normally a straightness of 50 nm per 25 mm to 3 nm per 3 mm.

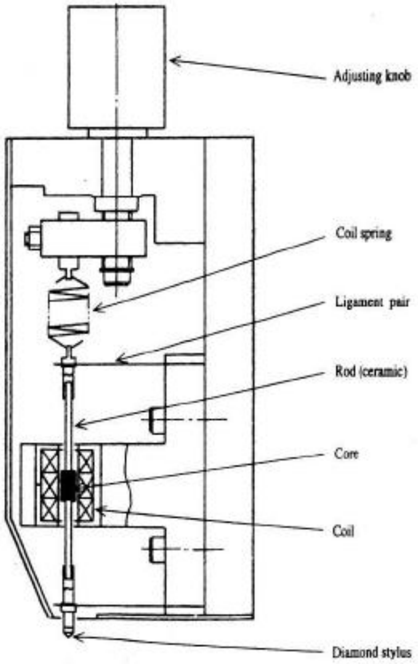

Fig. Surfcorder ET (Kosaka Laboratory Ltd). Stylus—transducer assembly, showing stylus support mechanism.

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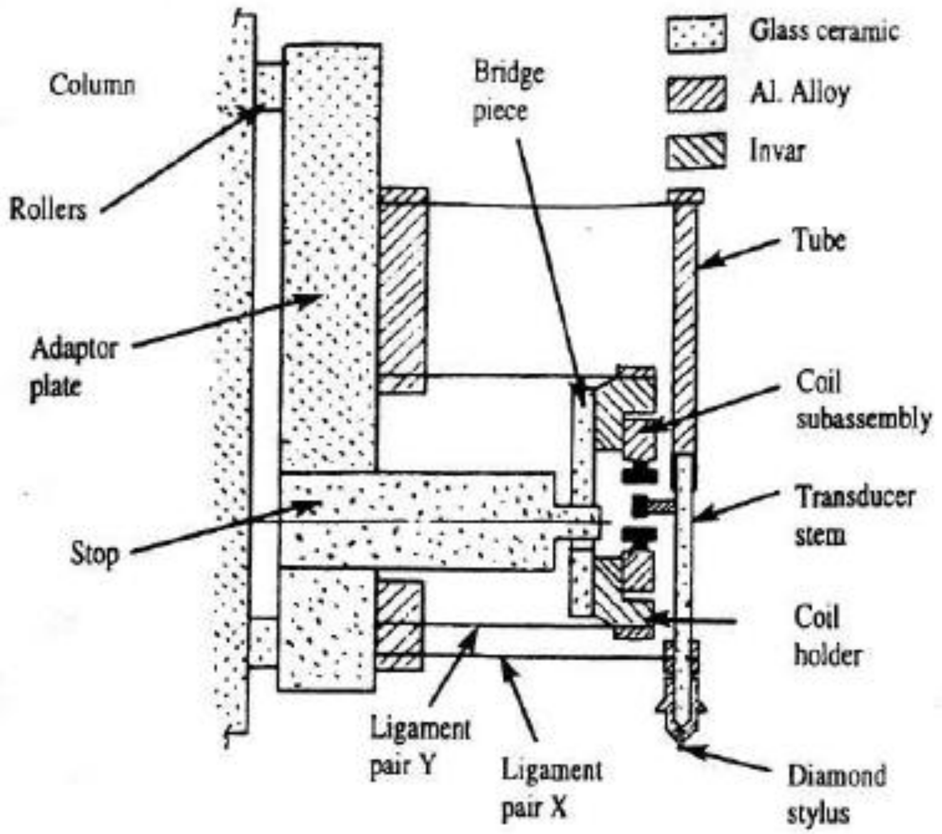

Fig.9 Nanostep (Rank Taylor Hobson Ltd). Transducer assembly, showing materials used in measurement loop.

Feed unit for detector unit and horizontal resolution

- An example of a feed (or traverse) unit is given in Fig. The guide mechanism consists of a precision-machined sleeve and guide rod; the sleeve, which holds the detector unit, slides along the fixed guide rod and reads the feed distance on a digital scale.

- The feed motion has a straightness given by the formula 0.05 + 1.5L/1000 µm, where L (mm) is the feed distance (i.e. Measurement). The maximum horizontal resolution is 0.1-0.05 µm

Feed unit for sample and horizontal resolution

- **The advantage of this kind of feed unit is that it can be designed and fabricated as a separate unit. It is connected to the instrument's main body by a three- point mounting so as to minimize force and heat deformations.**

- **A special material is used for the guide plane to provide smoother sliding, and measures have been taken to prevent vibrations that accompany the feed motions.**

- **Instead of taking direct measurements of the feed distance. In these units too the horizontal resolution of the feed distance is 0.1 µm, limited by the resolution of position detection.**

Feed unit for sample and horizontal resolution

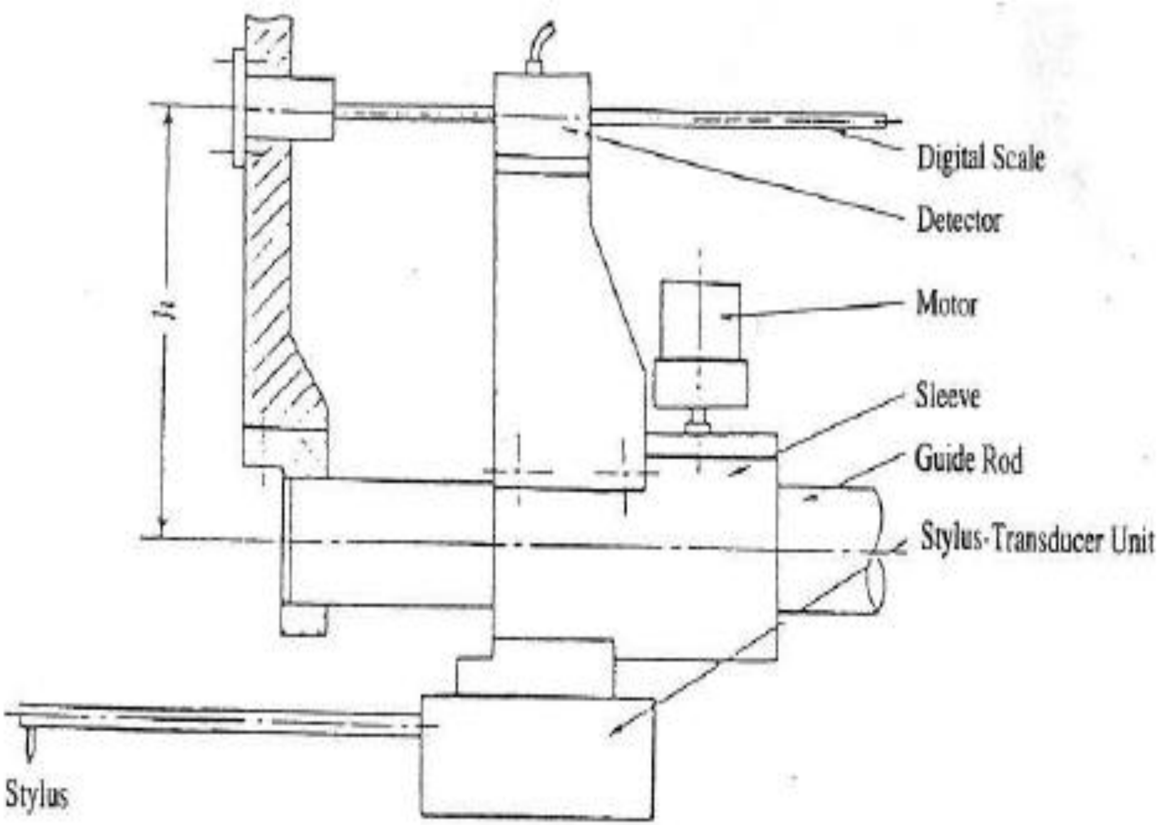

Fig. 10 Surfcorder SE (Kosaka Laboratory Ltd). Mechanism of traverse unit.

Feed unit for sample and horizontal resolution

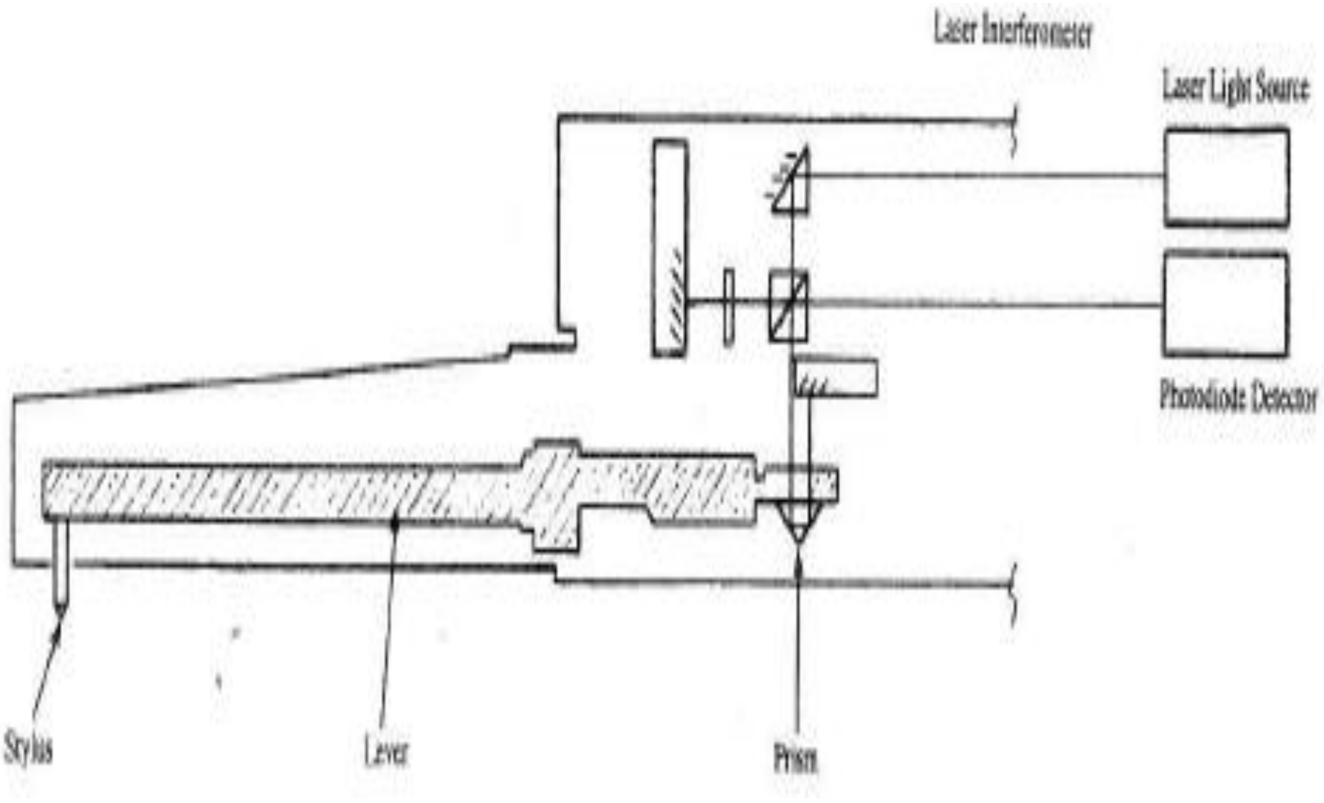

Fig. 11 From Talysurf S5 (Rank Taylor Hobson Ltd.) Schematic diagram of laser pickup

Feed unit for sample and horizontal resolution

Other methods of converting the mechanical quantity

(a) Vertical displacements

With a small transducer, it is possible to measure only a narrow range. To overcome this limitation, an instrument (Form Talysurf Model S5) that converts the vertical movement of the stylus into motion of interference fringes has been developed. It can measure a range of 6 mm with a vertical resolution of 10 nm. As shown in Fig.when the stylus, which is connected to a small prism, moves vertically, the optical path length in the laser interferometer changes, causing the interference fringes to move. This movement is measured to determine the distance travelled by the stylus.

Feed unit for sample and horizontal resolution

(b) Detection of horizontal position

One commercial product makes measurements with 8 nm resolution by allowing a semiconductor laser to impinge on a hologram grating and then utilizing the resulting interference of the diffracted light.

(c) Capacitance-type sensors

Non-contact capacitance-type sensors are now often used for position measurements in precision transfer devices and measurements of the dynamic characteristics of rotating samples.

A schematic drawing of such an active-probe sensor (ADE Corporation, USA) is shown in Fig

Feed unit for sample and horizontal resolution

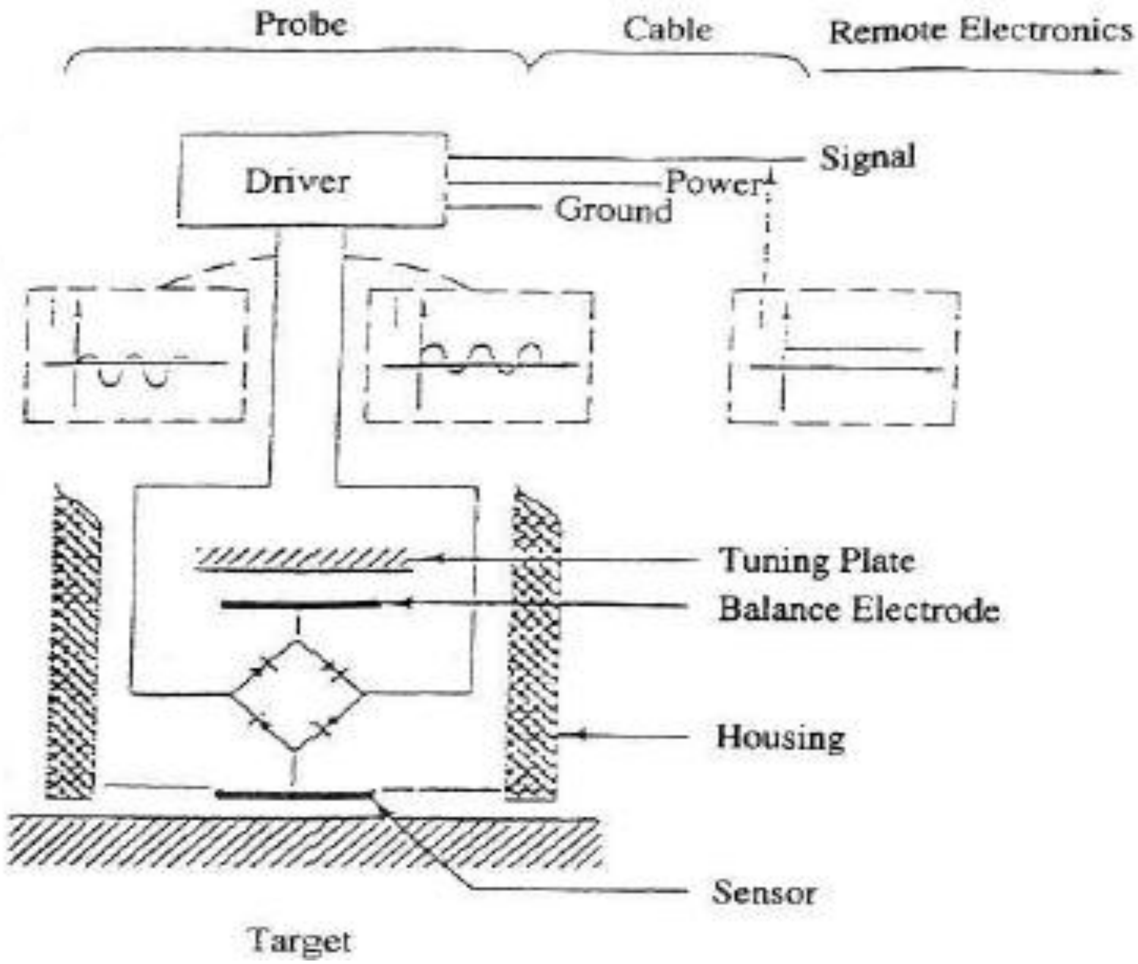

Fig. 12 Micro Sense-Active Probe (ADE Corporation). Simplified schematic diagram of 'active probe'.

Feed unit for sample and horizontal resolution

- It houses a sensor electrode and a balance electrode which provides the reference capacitance; the capacitance difference is used to make measurements.
- This probe yields an output inversely proportional to the distance between the sensor electrode and specimen surface (mean surface).
- This output is linearized (with a standard linearity of ±0.2%) by a linearizer circuit and then displayed. Although the static resolution is generally considered to be 10 nm at the most, in one instance in which the transfer position for a precision transfer device was measured, a resolution of 1 nm was obtained

Optical measuring systems

Precision measurement is essential for almost all nanometre-order processing. Non-contact, especially optical, measuring systems are now greatly needed in this particular field.

1. Laser interferometer

- Most ultra-precision processing systems have their own high-precision scales integrated with the machine tool or stand-alone measuring instruments in the inspection room
- The coherence of laser sources permits fringe counting systems with a range up to 50 m. Over the lifetime of the laser tube, the laser wavelength can remain stable to one part in 108 or better.

Optical measuring systems

- The most popular type of laser interferometer uses a heterodyne method with a two-wavelength Zeeman laser or an AO (acousto-optical) element to obtain accurate phase information
- The main drawback of interferometer systems of nanometre accuracy used in the free atmosphere is the necessity to correct for the refractive index of the air, which can change by one part in 105 under the usual conditions.
- Calculation of and correction for the refractive index by simultaneous measurement of air temperature, pressure, humidity, etc.

Optical measuring systems

(2) Optical figure-measuring instruments

- For measurement the figure of ultra-precision machined surfaces, optical interference wavefront detectors are widely used. They are mainly based on the Michelson, Fizeau, Mach-Zehnder, or Young interferometers or holography.

- The Fizeau-type interferometer with a laser source as shown in Fig.13 gives a relatively stable interferogram and is one of the most useful instruments in optical and precision machining workshops.

Optical measuring systems

All the interferograms in every scanning position are detected by a CCD camera and processed in a digital computer to obtain a figure map of nanometre-order resolution.

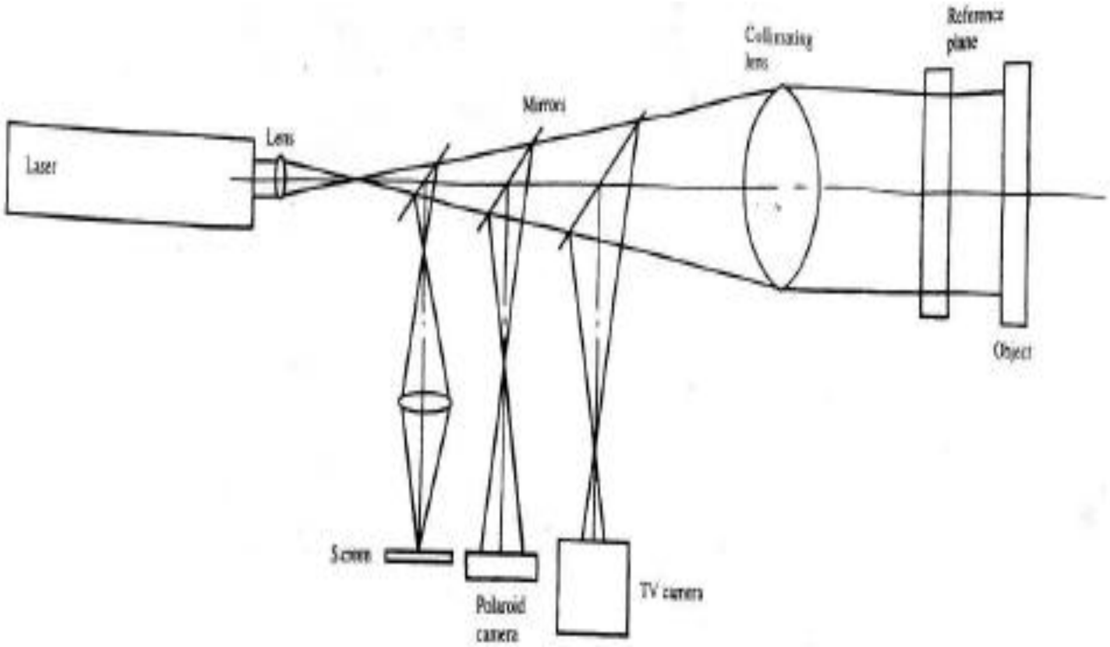

Fig.13. Laser interferometer for figure measurement

Optical measuring systems

- Like the DMI interferometer, the simultaneous phase shift interferometer (SPSI) of Michelson type(3), shown in Fig. below has the ability to make accurate phase measurements in dynamic environments where fringe patterns are rapidly changing.
- The SPSI uses a stabilized single frequency He—Ne laser and four CCD cameras. Interference fringes at each of the four cameras are phase-shifted 90 degrees relative to one another using polarization techniques
- The Micro PMI compact Fizeau interferometer with the same principle as the SPSI can measure surface height to better than 10 nm accuracy and is now commercially available.

Optical measuring systems

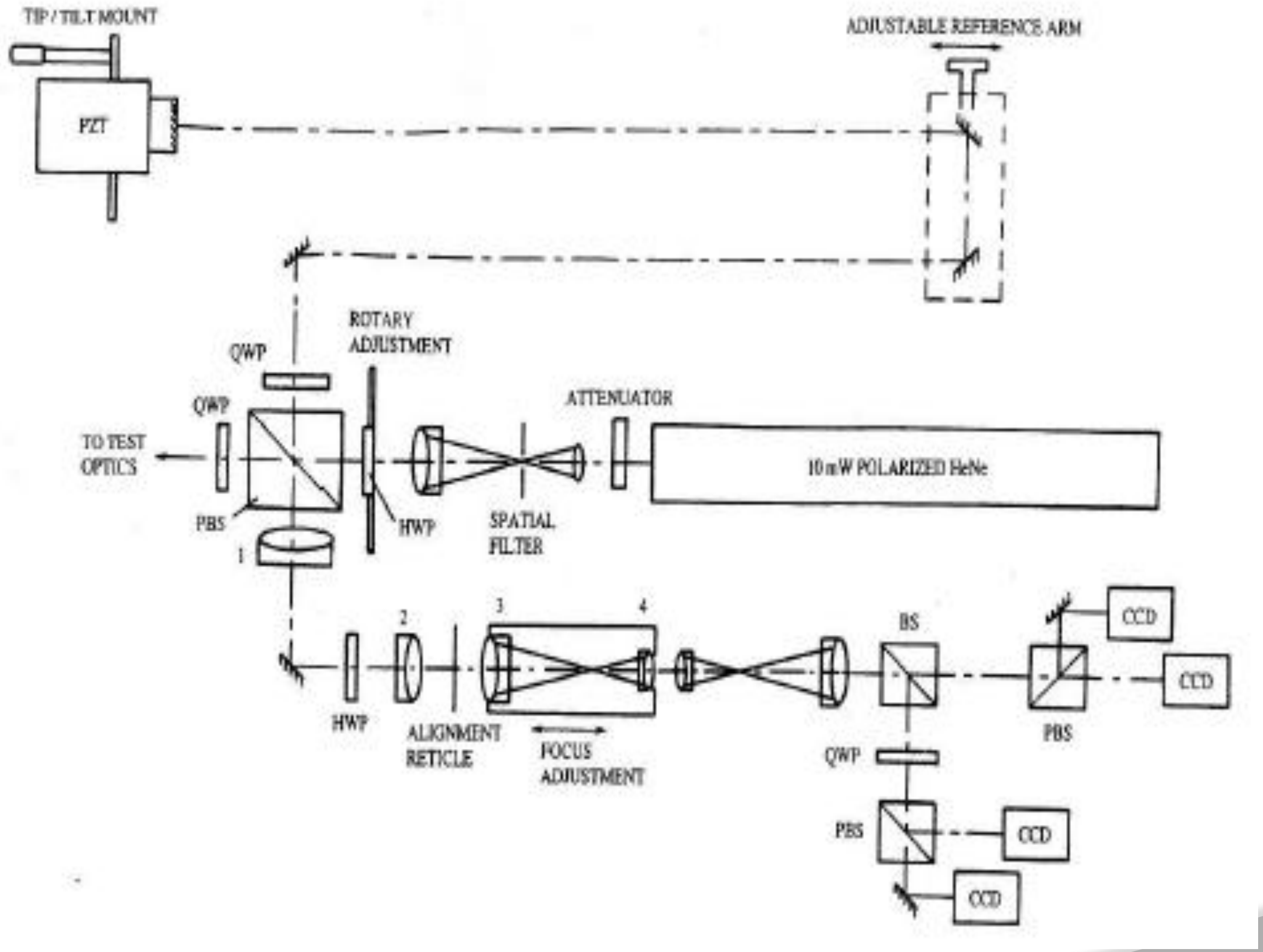

Fig. Optical layout of the simultaneous phase shift interferometer (SPSI).

Optical measuring systems

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Optical measuring systems

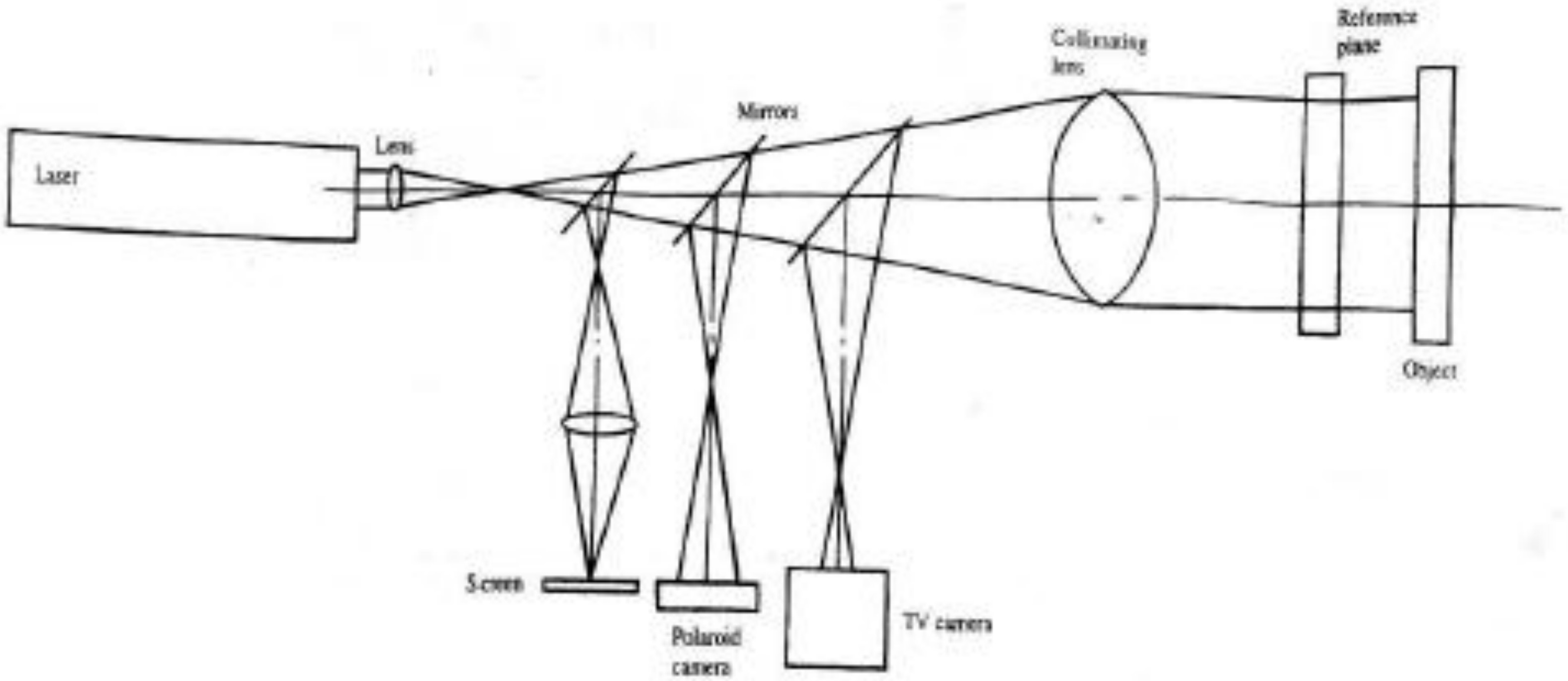

Fig.Laser interferometer for figure measurement

Optical measuring systems

- For accurate phase measurements of large optics over long optical paths, as explained above.
- Like the DMI interferometer, the simultaneous phase shift interferometer (SPSI) of Michelson type(3), shown in Fig. 13, has the ability to make accurate phase measurements in dynamic environments where fringe patterns are rapidly changing.
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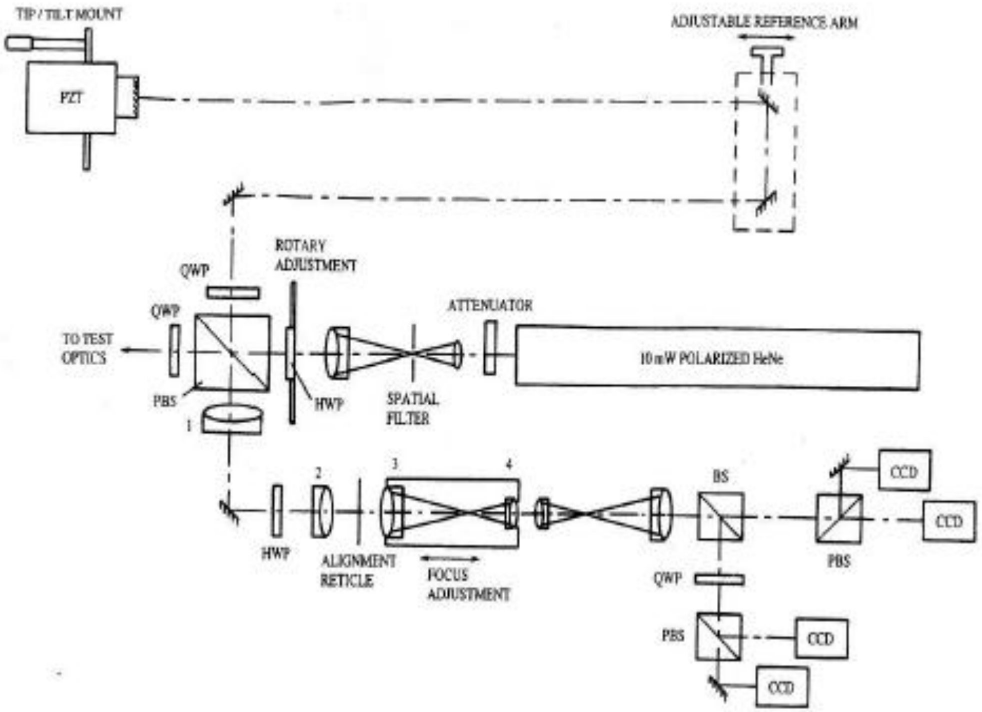


Fig. Optical layout of the simultaneous phase shift interferometer (SPSI).

Optical measuring systems

(3) Optical surface roughness-measuring instruments

- Hitherto, surface roughness has been measured primarily by stylus instruments, as a convenient and versatile method
- Optical stylus focus error detection and optical interferometers seem the most promising techniques for practical applications.
- Astigmatism, critical-angle, and knife-edge methods are typical examples of the optical stylus technique, and micro-Fizeau, Mirau, and Michelson instruments are typical interference profilometers.

Optical measuring systems

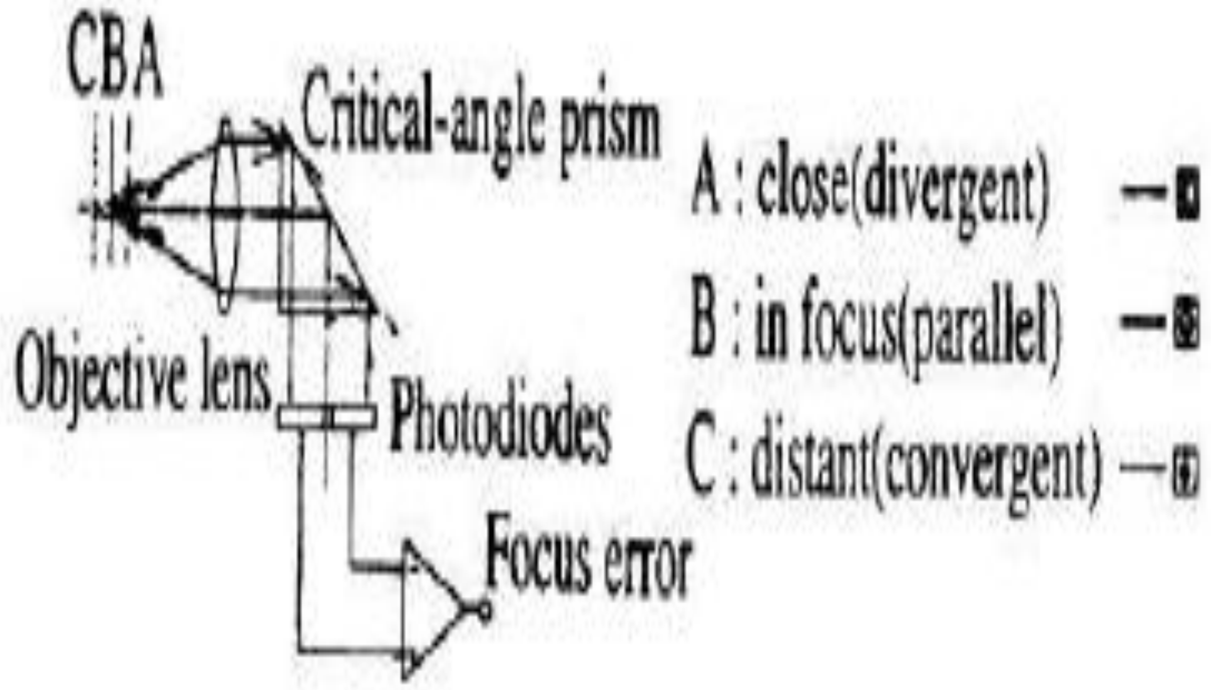


Fig. Principle of the critical-angle method.

Optical measuring systems

- The principle of the optical stylus using the critical- angle method is shown in Fig. If the surface under test is at the focus of the lens at B, the laser light passing through the objective lens is converted into parallel flux.
- When the object surface is at position A close to the lens, the light diverges after passing through the lens.
- As a result, a difference in the output of the photodiodes is created, thereby producing an out- of-focus signal

Optical measuring systems

As shown in Fig. the high-precision optical surface sensor (HIPOSS)(4) has a half-mirror to split the optical path into two total-reflection prisms and split detectors so as to avoid any effects of object surface inclination on the measured result.

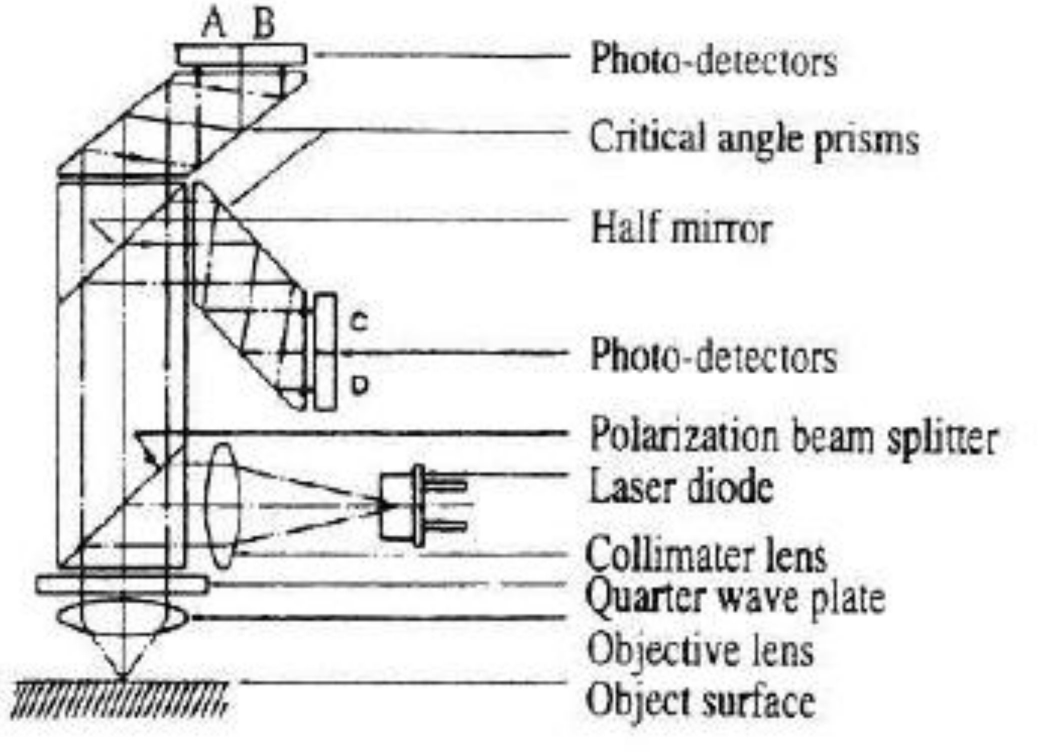


Fig. Optical path of the high-precision optical surface sensor (HIPOSS).

Electron beam measuring systems: / SEM and TEM

- **Since the electron beam has a short wavelength, it provides a much higher resolution than light when used in a microscope.**

- **The line-width measurement system and the electron beam tester are established measuring systems using electron beams, both of which were developed for the semiconductor industry.**

- **When ‘measurement system’ is defined to include surface analysis systems and microscopes, EPMA (electron probe microanalyser), SAM (scanning auger microscope), SEM and TEM are all measurement systems effectively used in the field of industrial measurement.**

Electron beam measuring systems: / SEM and TEM

Wafer inspection systems

(a) Required resolution

- Large-scale integration of devices and improvement of their functions and performance have taken place rapidly in the semiconductor industry.
- Along with this progress, the minimum-sized unit for device design (called the 'design rule') is becoming smaller year by year.
- For example, with the 256M DRAM now under development, this size is ~ 0.2µm. The size of defects or errors that influence the electrical properties of devices is said to be 1/10 of the design rule.

Electron beam measuring systems: / SEM and TEM

(b) Need for low accelerating voltage and its influence on resolution

- **Wafer inspection systems carry out dimensional measurements and morphological observations on resist patterns and etching patterns formed on Si wafers.**
- **Moreover, when a high energy electron beam is targeted on an MOS transistor, a major component in today's semiconductor devices, the electrical properties of the transistor deteriorate or are destroyed.**
- **The SEM's probe size d (which determines the resolution) can be approximately expressed by the following equation(2):**

$$d^2 = \left(\frac{2}{\pi\alpha}\sqrt{\frac{1}{B}}\right)^2 + \left(\frac{1.22\lambda}{\alpha}\right)^2 + \left(C_c\alpha\frac{\delta V}{V}\right)^2 + \left(\frac{1}{2}C_c\alpha^3\right)^2$$

Electron beam measuring systems: / SEM and TEM

(c) Field emission electron gun (FEG)

- The field emission electron gun is characterized by high brightness and small energy spread. The brightness is as high as 108 A cm-2 sr-1 even at 1 kV (in contrast to about ~ 103 for a TEG).

- Therefore, under typical operating conditions (I = 10 pA, α = 5 mrad), the first term of eqn is 0.4 nm, which can be neglected compared with the other terms.   is ~ 0.3 V for a cold FEG and ~0.5 V for a thermal FEG.

- These values are 1/7 and ¼ of that of a TEG. Hence the use of the FEG makes it possible to improve considerably the resolution at low accelerating voltages.

Electron beam measuring systems: / SEM and TEM

(d) Improvement of objective lens aberrations

- Since the conventional SEM is designed for multipurpose use, its objective lens is not optimal at low accelerating voltages.

- If the objective lens is specifically designed for use at low accelerating voltages, this creates more room for design improvements.

- For the magnetic lens it is known that the larger the excitation parameter (J2/V), where J is the number of ampere- turns, the higher is the lens performance. At low accelerating voltages, a large J2 / V value can be obtained with a relatively small J.

Electron beam measuring systems: / SEM and TEM

Transmission electron microscope (TEM)

- The TEM is the only instrument that allows observations of the internal structure of a specimen obtained with an electron beam line-width measurement system incorporating the lens shown in Fig. and thermal FEG (V = 0.8 kV).

- With the recent advent of focused ion beam (FIB) equipment, however, a selective thinnning technique has been developed for TEM observation. Hence major efforts are now' being made to use the TEM to inspect the internal structures of semiconductor devices.

Electron beam measuring systems: / SEM and TEM

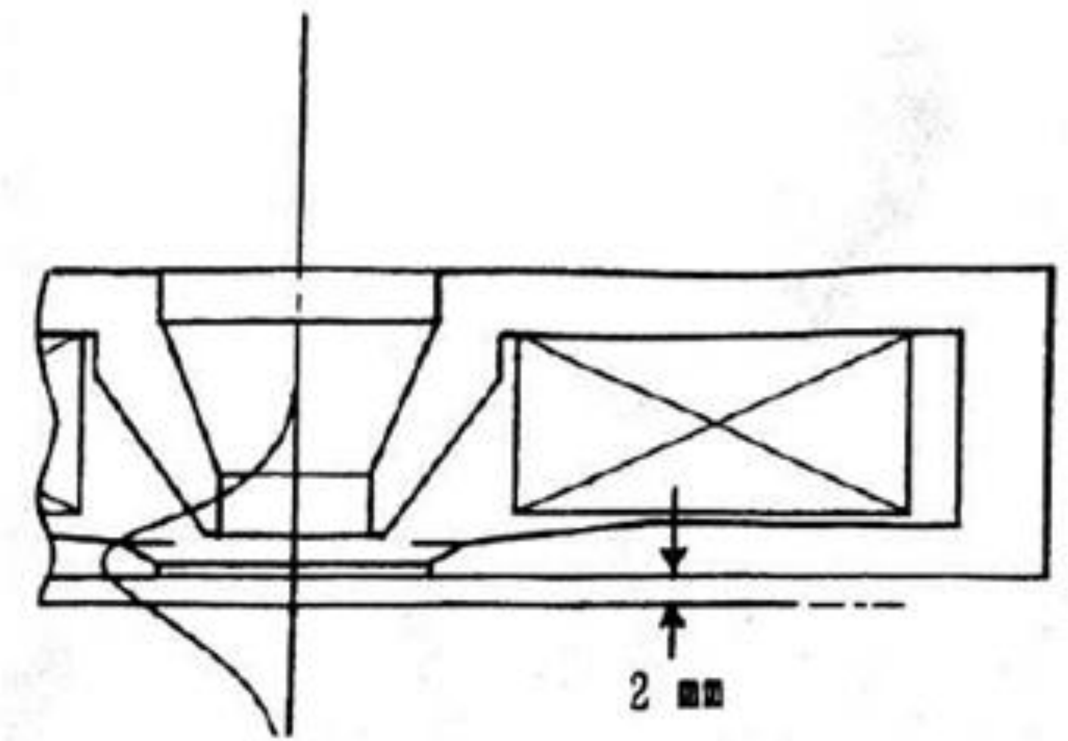


Fig. Objective lens for line-width measurement system.

Pattern recognition and inspection systems

Basic concept of pattern recognition systems

- Pattern recognition is the technology of analysing pictorial information using digital computers.
- Although it was once a very specialized and expensive technology, with rapid advances in digital computers.
- pattern recognition technology has emerged from the research laboratory and is being used in a wide array of applications such as FA (factory automation), OA (office automation), CG (computer graphics), medical systems, publishing, security, remote sensing, and the arts

Pattern recognition and inspection systems

A basic pattern recognition system is shown in Fig. 19. In general, such a system consists of an illumination source, a sensor, an image processor and a display unit.

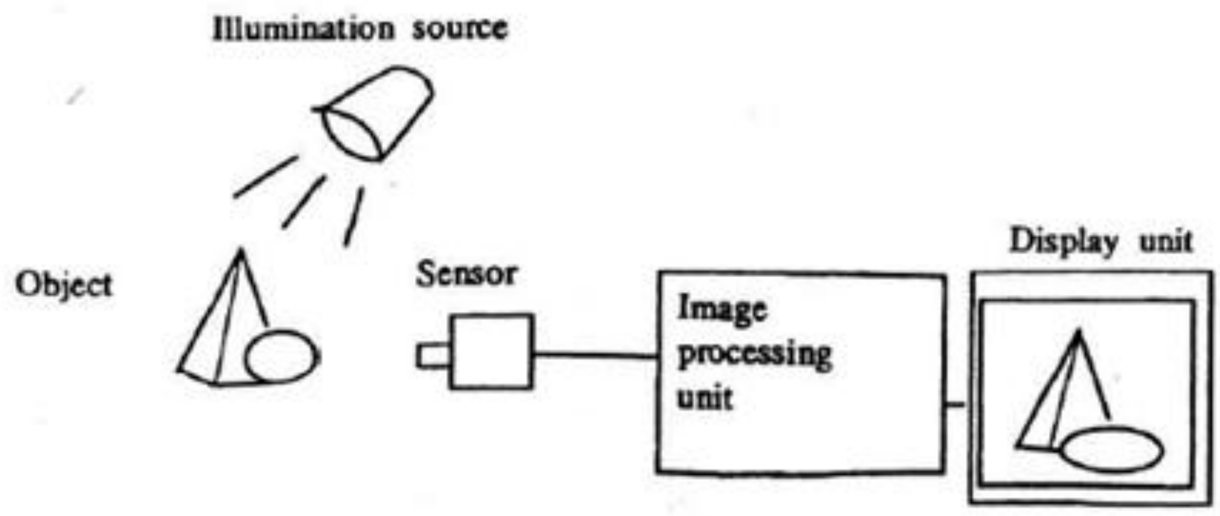


Fig. Pattern recognition system.

Pattern recognition and inspection systems

- How the image processing unit handles the data is shown in Fig. 20. This system consist of an A—D (analogue—digital) converter, image memory, image processor, D—A converter, CPU, program memory and keyboard.

- Image data observed by a camera are digitized by the A—D converter and stored in the image memory.

- The data are then transferred to the image processor to be processed by an algorithm, and are reconverted to analogue form by the D—A converter and displayed.

Pattern recognition and inspection systems

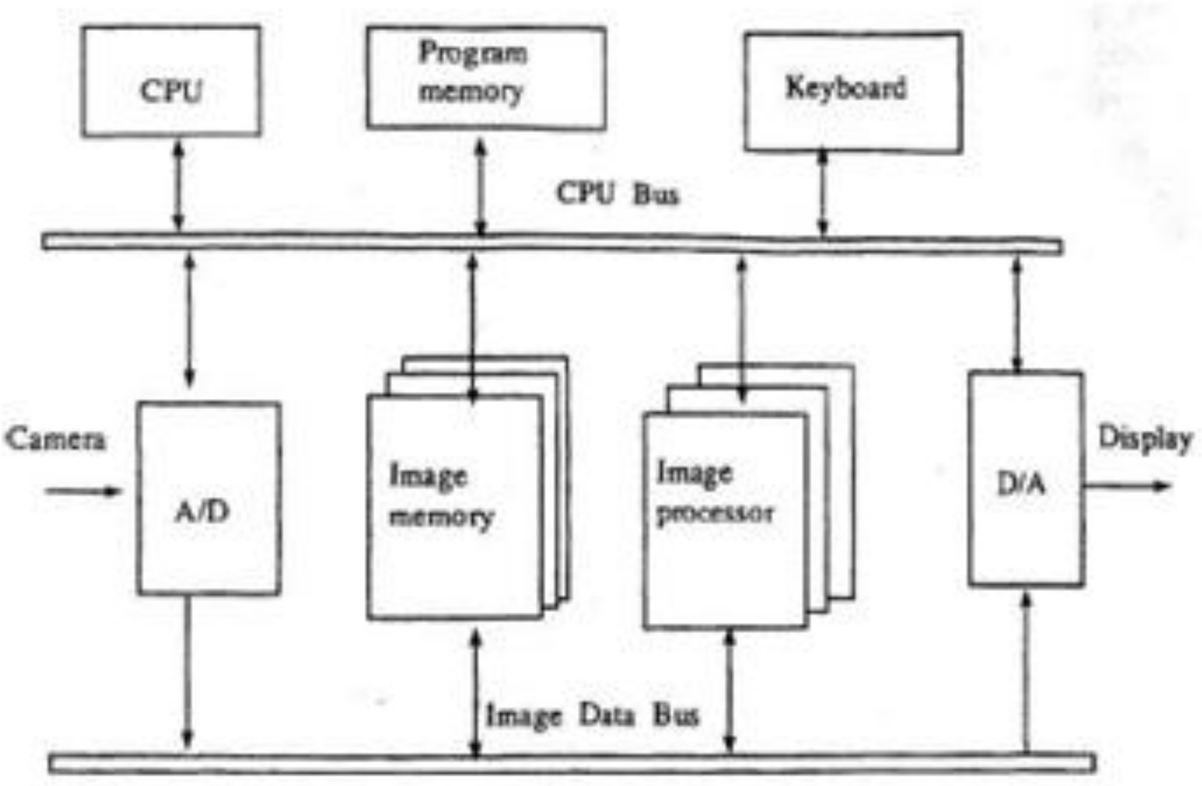


Fig. Block diagram of image processing unit.

Pattern recognition and inspection systems

- **The image data consist of two-dimensional numerical data corresponding to an observed image.**
- **The pixel is the minimum sampling unit for digitization; one pixel has two dimensional position data and one numerical datum which represents the observed brightness, as shown in Fig.**

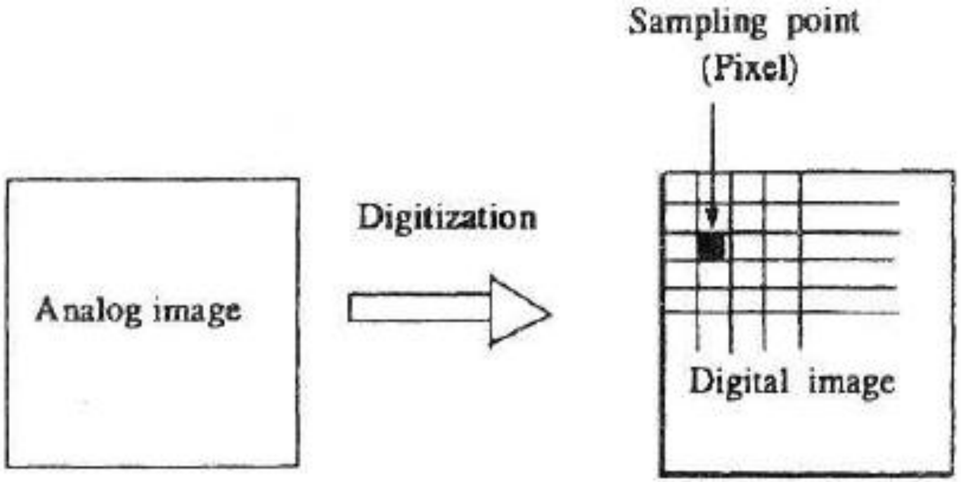


Fig. Representation of image data.

Pattern recognition and inspection systems

- **The pre-processing algorithm accomplishes normalization by geometrical transformations, sharpening by filtering, and contrast enhancement by grey- level transformations, and elimination of noise by smoothing.**
- **The main algorithm also carries out basic operations such as binarization, affine transformation, grey-level transformation, filtering, two-dimensional Fourier transformation, and pixel operations for addition, subtraction, multiplication, and division.**

Pattern recognition and inspection systems

- **Examples of image processing algorithms**
- **Figure shows the visual images of an ARI (assembly robot with intelligence). The ARI has two vision systems, corresponding to the left and right eyes. The pair of stereo images from the two vision systems are analyzed together**

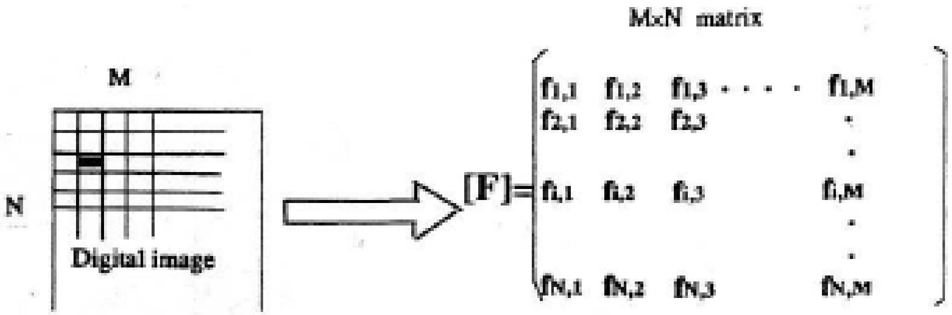


Fig.22. Image data representation by an M x TV matrix.

UNIT – V

LITHOGRAPHY

Introduction about Photolithography

- Since photolithography was first applied to semiconductor circuit fabrication, the performance of semi-conductor circuits has been extended up to ULSI. Photolithography is the most important and key Technology in the semiconductor fabrication system.

- Photolithographic technology has been improved in accordance with the demands of higher circuit integration, and now lines of width several hundreds of nanometres have been fabricated by photolithography.

- The optical wafer stepper, referred to simply as the stepper, is used on almost all production lines for mass production of ULSI as the photolithographic device. The stepper involves many of the most advanced component technologies, including nanotechnology.

Introduction about Photolithography

Optical configuration of the stepper

- **The optical system of the stepper is shown in Fig1 The key component is the projection lens for imaging the mask pattern on to the wafer with some reduction ratio**

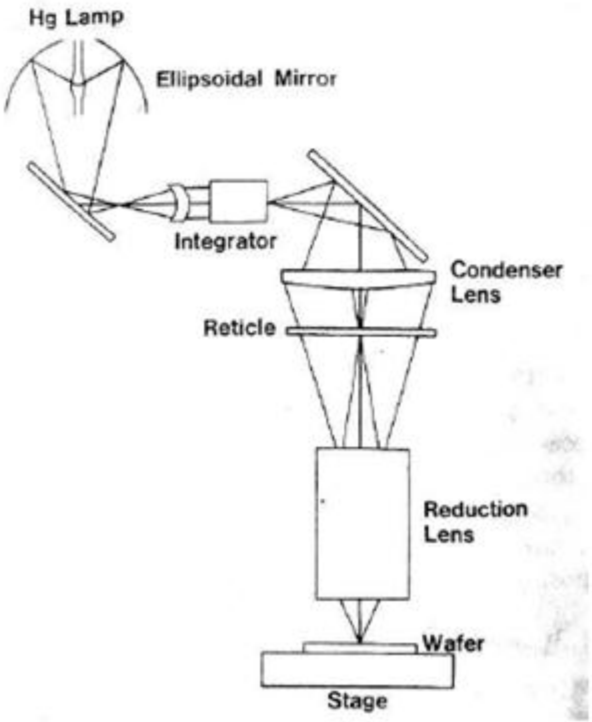


Fig.1 Optical system of water stepper.

Introduction about Photolithography

- Theoretically, the resolution of the lenses is defined by the formula
  - $R = K. \lambda / NA$
- where R is the resolution (nm), AT is a process factor, a constant defined by the process of pattern duplication and equal to 0.8 under production conditions and 0.65 in R & D, λ is the wavelength of the light source (nm), and NA is the numerical aperture (= 1/ cosθ, where θ is the angle formed by the optical axis and the outermost light beam to the image).

Introduction about Photolithography

- **A lens system is made up of about 30 component lenses, each of which has a maximum diameter of 250 mm and a maximum mass of 10 kg. The total mass of the whole lens system is up to 500 kg.**

- **The basic configuration of the excimer stepper is almost the same as the ordinary stepper except for the light source. A KrF excimer laser (248 nm) is now in use for test production of ICs, and an ArF excimer laser (193 nm) is under development .**

- **A kind of optical monochromator is inserted in the cavity of the laser to achieve a narrow bandwidth.**

Introduction about Photolithography

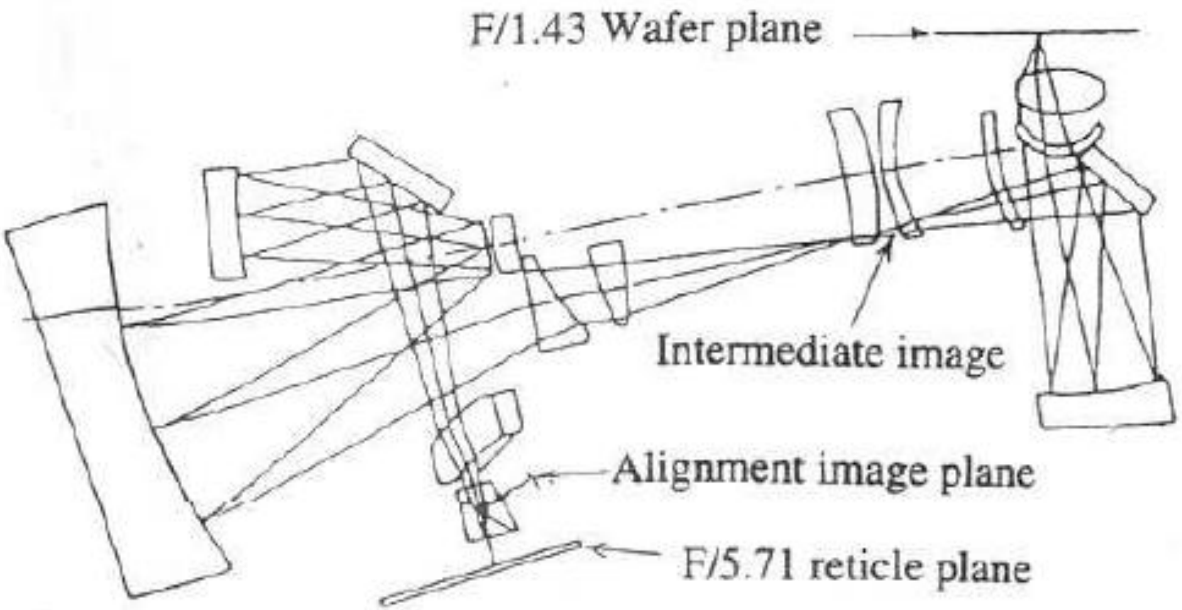


Fig.2. Optical system of mirror projection optics (Micrascan, Perkin-Elmer Co.).

Introduction about Photolithography

- Shorter wavelengths allow less material to be used in excimer laser projection lenses, owing to the low transparency of the materials at the excimer laser wavelength.

- Typical optical glasses green soda-lime glass and white crown glass (BK7) - cannot be used in the ultraviolet region. Quartz (SiO2) and fluorspar (CaF2) are possible candidates.

- A combined system using reflecting mirrors has been developed to reduce the number of lenses. An example is shown in Fig.2. A problem is the small exposure area with this system, so scanning methods have to be used.

Introduction about Photolithography

- **Alignment system**
  - Integrated circuits are fabricated by applying some 10 to 15 different pattern masks for the multilayered structure.

  - The alignment between a previously exposed pattern on a wafer and the succeeding pattern on a mask that will be exposed on the wafer is a critical factor determining the minimum pattern width.

  - The stepper has a number of alignment systems, each with a certain attainable accuracy. Wafer pre-alignment is achieved by means of two rolling pins fitting the facet of the wafer within ±3 µm

Introduction about Photolithography

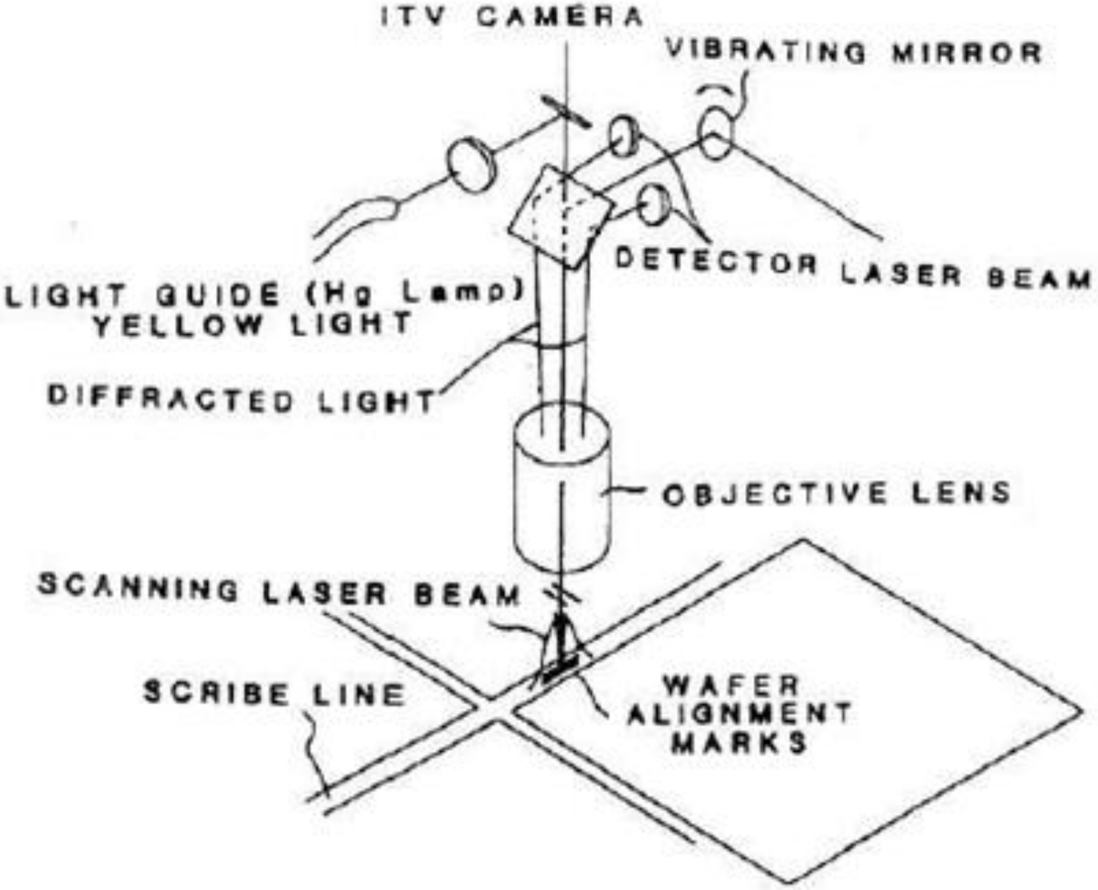


Fig. 3. Principle of a wafer alignment system.

Introduction about Photolithography

- **Essentially, alignment is achieved by detection of the centre of the alignment pattern and adjustment of the position of either wafer or mask so as just to overlap each other.**

- **The same technique is used in the alignment system of IC steppers, although some improvement has been achieved.**

- **A vibrating mirror in the light path as shown modulates the illuminating position on the wafer sinusoidally**

- **The signal from a photo detector is amplified and fed to a phase-sensitive detector (PSD).**

Introduction about Photolithography

- An example of the chip alignment system is shown in Fig.4. The laser beam illuminates the chip alignment pattern through the projection lens.

- The diffracted light from the wafer returns along the same optical path and is split by the beamsplitter to the detector.

- The spatial filter stops the zero-order diffracted light to eliminate effects due to the strong beam containing error factors through surface rough-ness or pattern irregularity.

Introduction about Photolithography

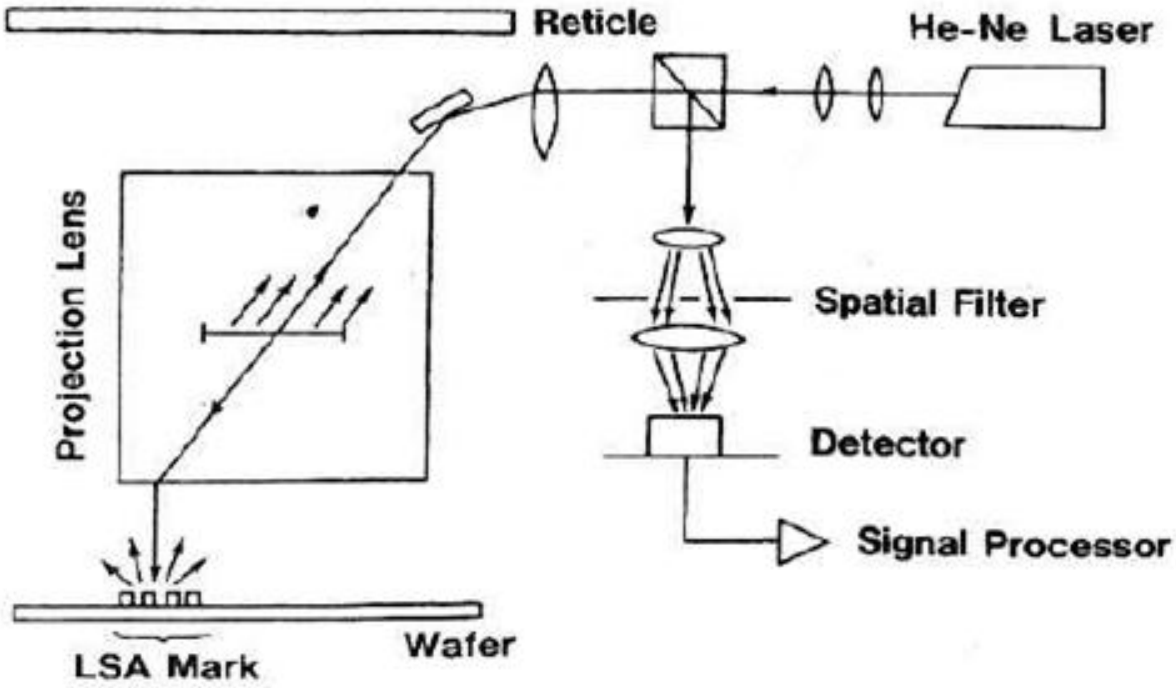


Fig.4 Principle of a chip alignment system.

Introduction about Photolithography

- **The mark is scanned by the stage motion. The signal from the detector shown in Fig.5 is interpolated by the fringe signal of the stage interferometer, allowing the accurate centre of the pattern to be detected. The total configuration of the alignment system is shown in Fig. 5.**

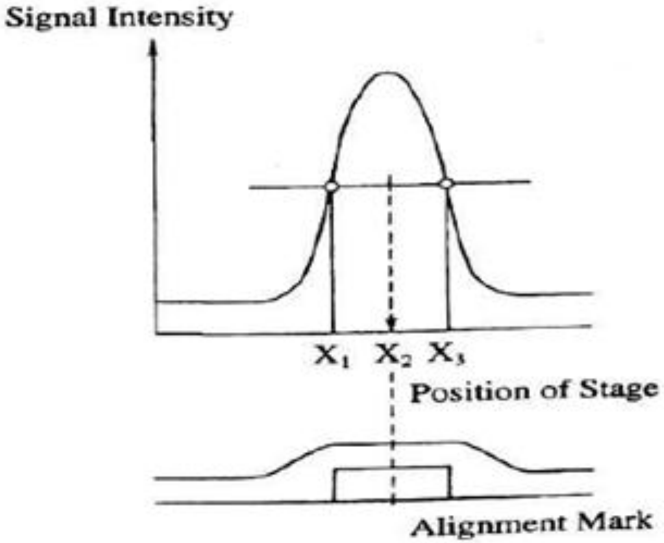
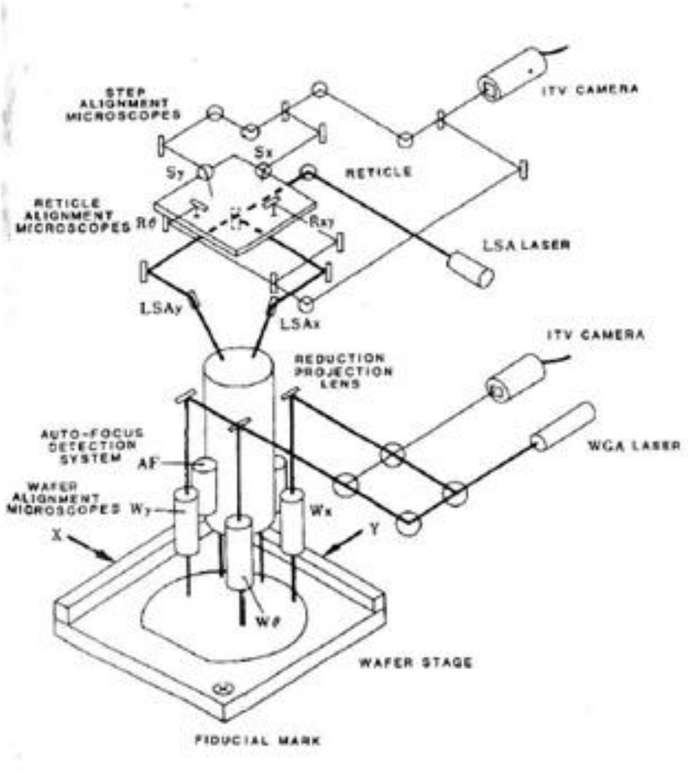


Fig 5. Chip alignment signal processing.

Introduction about Photolithography

- The mark is scanned by the stage motion. The signal from the detector shown in Fig.5 is interpolated by the fringe signal of the stage interferometer, allowing the accurate centre of the pattern to be detected. The total configuration of the alignment system is shown in Fig. 6
- .



Introduction about Photolithography

Autofocus, auto-levelling system

- The depth of focus at which a specific resolution can be obtained is defined by
- DOF = k.1/λ.(NA)2
- Since high-NA lenses are used for high-resolution imaging, focusing is very critical. Line-width variation with out-of-focus displacement is shown in Fig. 10. Autofocusing systems are used in almost steppers.

Introduction about Photolithography

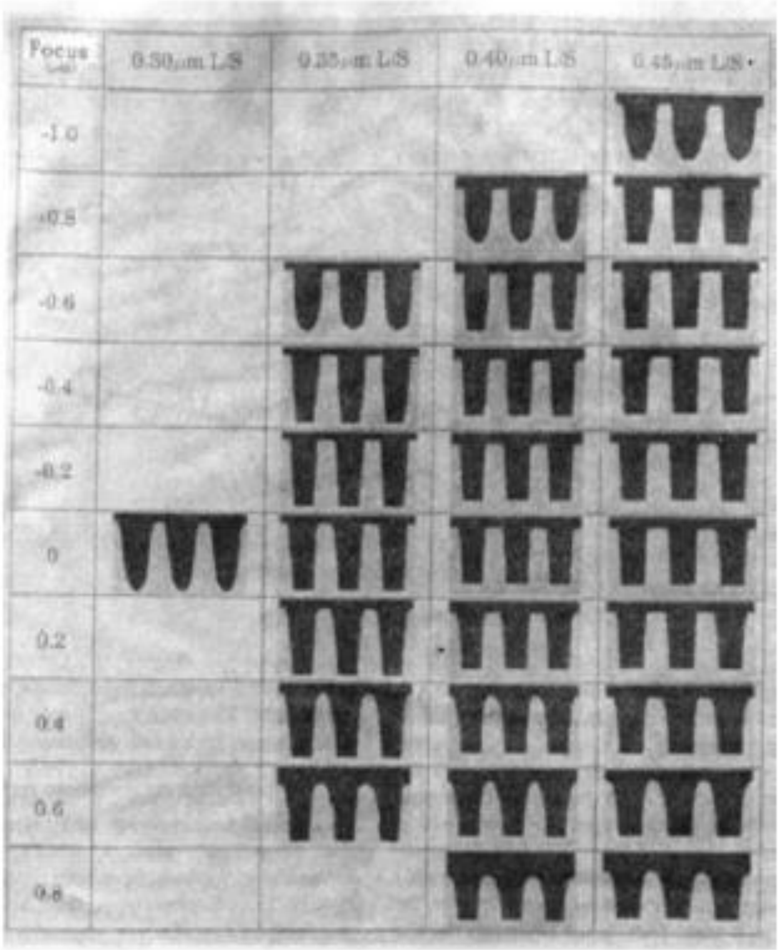


Fig.10. Line patterns as a function of focusing conditions

Introduction about Photolithography

Mechanical stage for wafer stepping and alignment

- The stage carrying the wafer needs to have both speed and high positioning accuracy to attain high resolution and high throughput.

- Position control is achieved as follows; a position command is given by a computer and the stage position is sensed by a laser interferometer with feedback to the controller, which drives the motor until the error between command and stage position is reduced to zero.

Introduction about Photolithography

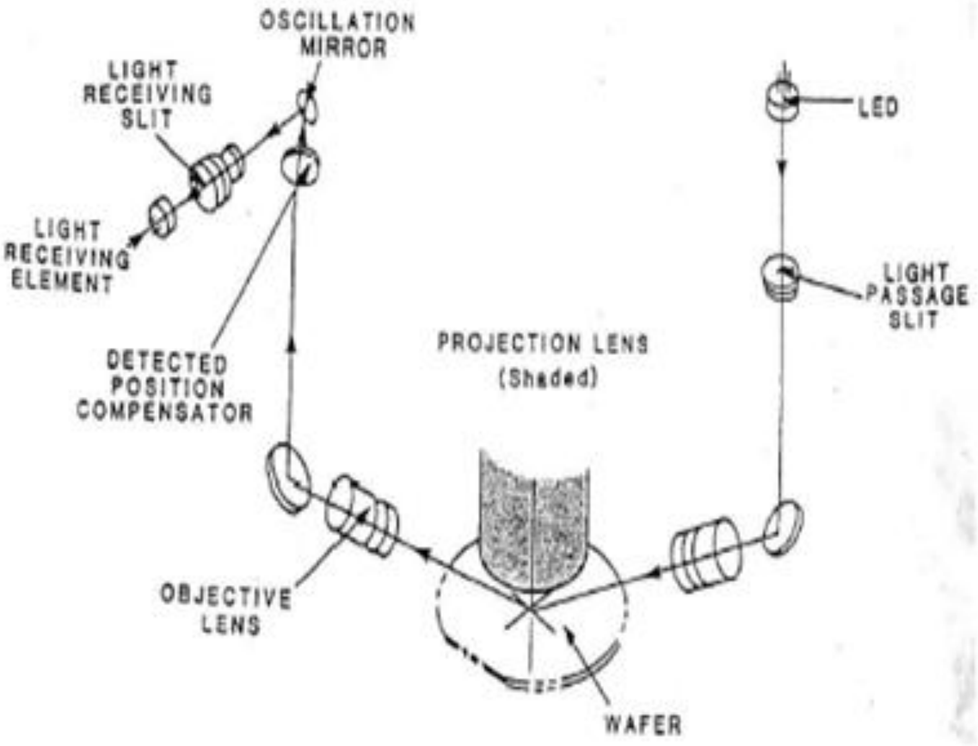


Fig.11. Configuration of an autofocus system.

Introduction about Photolithography

- **With a higher-resolution stepper, the step-and- repeat system cannot be used, because the exposure area is not able to cover a whole chip area with a resolution better than 0.25 µm.**

- **The lens or mirror projection system will be able to achieve imaging only in the slit zone covering part of a chip of size for example 22x4 mm.**

- **Then a slit-like image on the mask is projected on to the wafer, and the full image of the mask is exposed after scanning of the mask and wafer synchronously over a chip.**

Introduction Electron beam lithography

- Electron beam (EB) lithography has been an essential mask fabrication technology for ULSI devices since Bell Laboratories developed a high-throughput and reliable EB system, EBES1.

- It has been forecast that progress in the miniaturization of ULSI devices achieved by the revolution in optical lithography will result in a 1 Gbit DRAM.

- However, since optical lithography for a size of 0.25 pm is still under development, optical lithography is not always used in the development of 256 Mbit to 1 Gbit DRAM devices. Although the EB system throughput is very low, it is sufficient for use in R & D on devices because of its high-resolution capability.

Introduction Electron beam lithography

- The problem is that it is impossible for optical lithography to fabricate a pattern smaller than 0.15¬0.1 µm, owing to its resolution limitation. EB lithography, in addition to X-ray lithography, is a promising technique for such smaller patterns.

EB lithography for masks

- Figure shows a lithography scheme. Nowadays the main lithography technique is for an optical projection printing machine to duplicate a pattern from a mask of several fold magnification (reticle) on to a Silicon (Si) wafer.

- The reticle or mask is fabricated by the EB writing process. So far, a Gaussian beam system has been used for reticle-making in most mask shops

Introduction Electron beam lithography

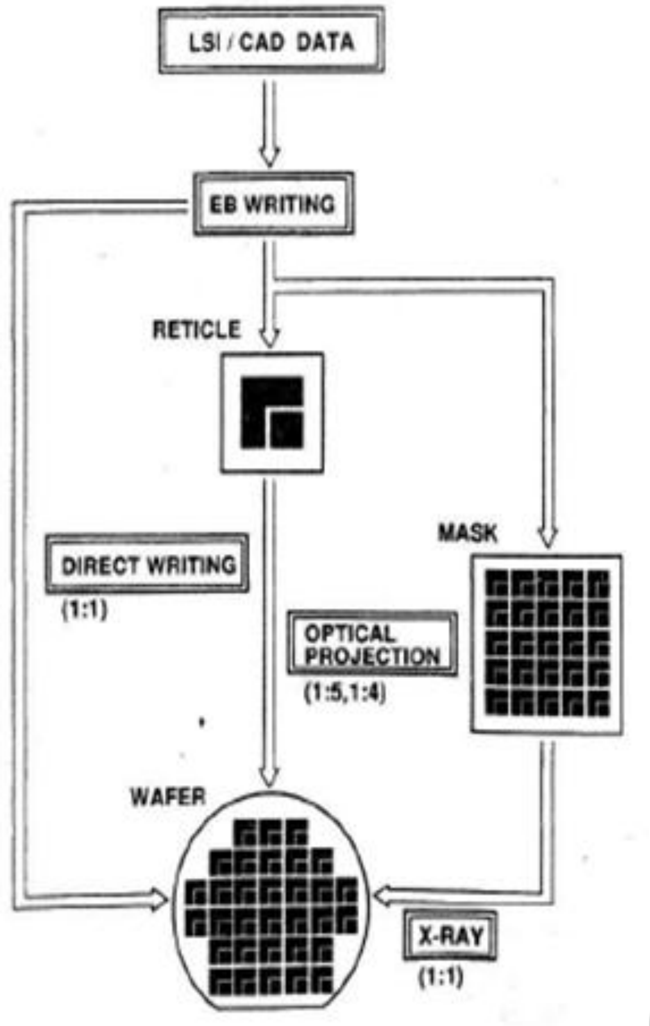


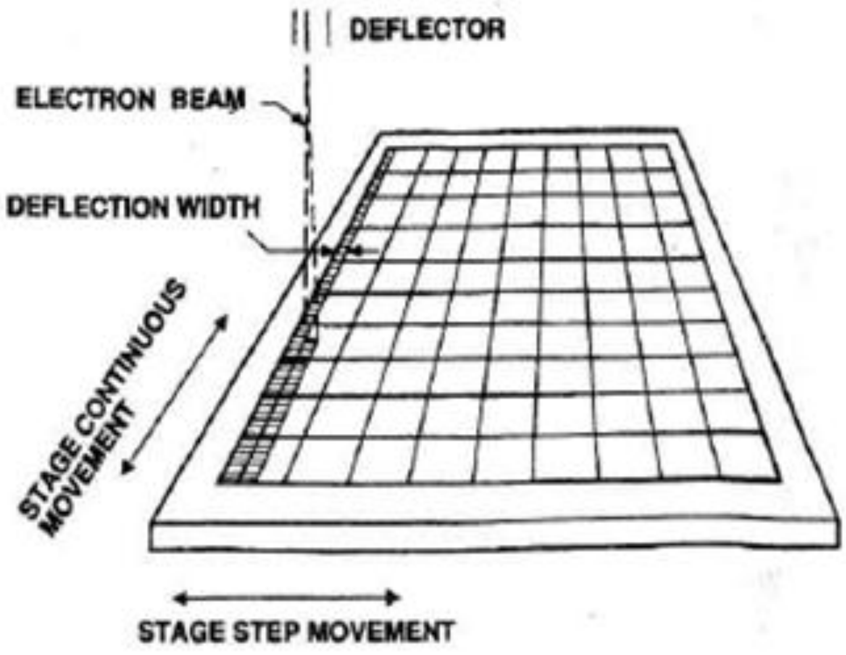
Fig.14. Lithography scheme

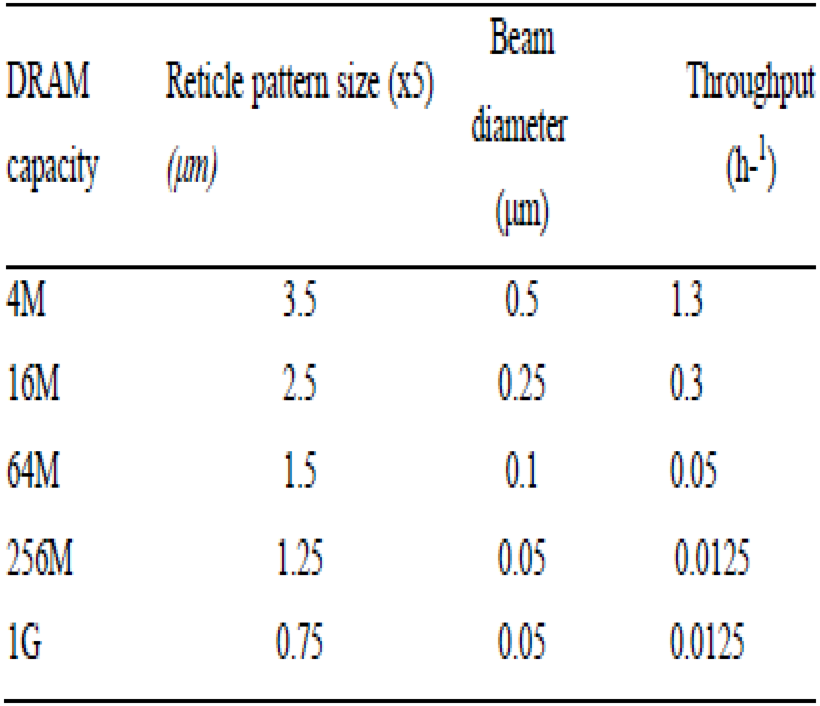
Introduction Electron beam lithography

- **Furthermore, the reticle writing speed is reduced by proximity effect correction such as a GHOST exposure method(3), by an increase in reticle size from 125 to 150 mm and also by phase-shifting mask writing, which requires about double exposure.**

- **A high-speed reticle writing system is therefore strongly required. MEBES (ETEC Co.) has been developed as a high-speed reticle writing system which adopts a Zr-O-W thermal field-emission electron gun.**

Introduction Electron beam lithography





DRAM capacity	Reticle pattern size (x5) (*μm*)	Beam diameter (μm)	Throughput (h-^{1})
4M	3.5	0.5	1.3
16M	2.5	0.25	0.3
64M	1.5	0.1	0.05
256M	1.25	0.05	0.0125
1G	0.75	0.05	0.0125

Fig.Writing method for reticle writing

Introduction Electron beam lithography

- Another method of achieving a high throughput system is to adopt the variably shaped beam (VSB) concept. The writing method for the EX-8 (Toshiba Co.) is shown in Fig. which adopts VSB, a continuously moving stage, and vector scanning (beam flies from pattern to pattern(6).

- The EX-8 has the ability to write a 1 Gbit DRAM-class reticle pattern, because the address size, corresponding to the beam size in a Gaussian beam system, is 0.01 µm.

Introduction Electron beam lithography

- A stripe stitching error arises from residual distortion of the main deflector after distortion correction, stage attitude control error, mechanical vibration between the electron optical column and the substrate, electrical noise, and beam drift.

- Furthermore, long-term stability of accuracy is required. It needs great effort to maintain an accuracy of 5x10-7 for a long time. Many monitoring systems for acceleration power supply, stage temperature, beam size, beam drift, and so on have been developed

Ion Beam Lithography

- This is a variation of the electron beam lithography technique, using an focused ion beam (FIB) instead of an electron beam. In a similar setup to scanning electon microscopes, an ion beam scans across the substrate surface and exposes electron sensitive coating.

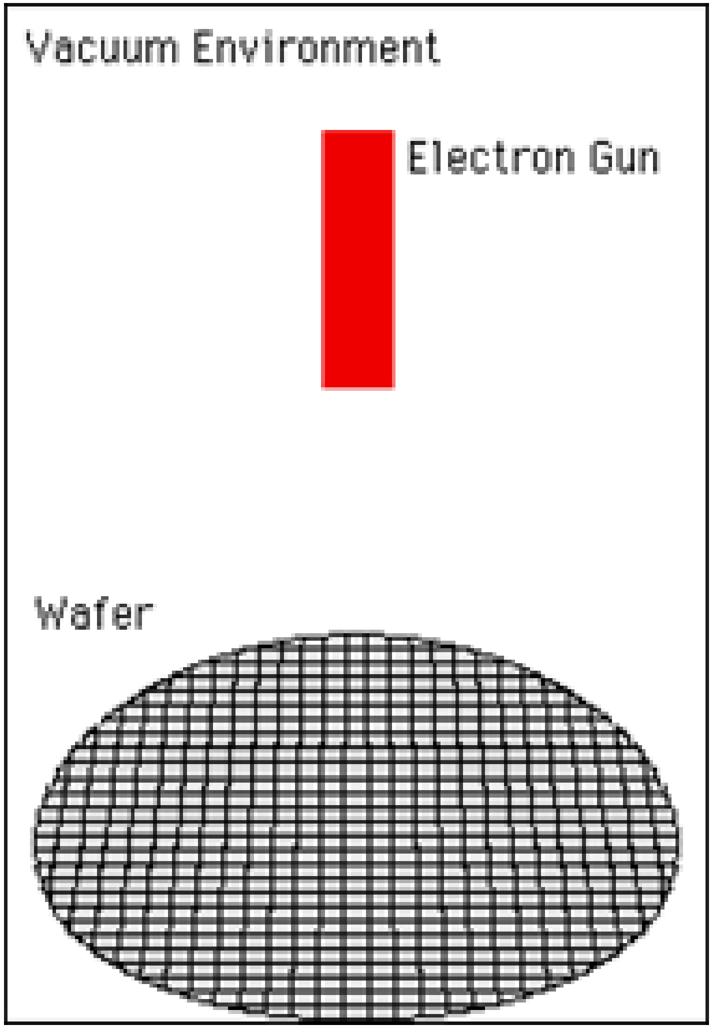
- A grid of pixels is superimposed on the substrate surface, each pixel having a unique address.

- There are two methods of scanning the beam over the substrate surface to write the pattern data. With raster scan, the electron beam is scanned across lines of pixels and the wafer is shifted to the next line. With vector scan, an area of an individual chip is selected, and the beam draws out the features in that area one-by-one.

Ion Beam Lithography

Advantages:

- Computer-controlled beam
- No mask is needed
- Can produce sub-1 µm features
- Resists are more sensitive than electron beam resists
- Diffraction effects are minimized
- Less backscattering occurs
- Higher resolution
- Ion beam can detect surface features for very accurate registration



Ion Beam Lithography

Disadvantages:

- Reliable ion sources needed
- Swelling occurs when developing negative ion beam resists, limiting resolution
- Expensive as compared to light lithography systems
- Slower as compared to light lithography systems
- Tri-level processing required

Optical Lithography

- The name optical lithography comes from the early application where the exposing energy was visible light. While those wavelengths can still be used, the push to reduce the size of feature sizes has lead to the use of shorter wavelengths to increase resolution.
- The process steps described below are superficial and require advanced levels of technology to be fully effective. There are many references available which more completely describe each process step.
- The first step in optical lithography is to create a mask. The mask substrate is commonly borosilicate glass or more recently fused-silica because of its lower thermal expansion coefficient and higher transmission at lower wavelengths.

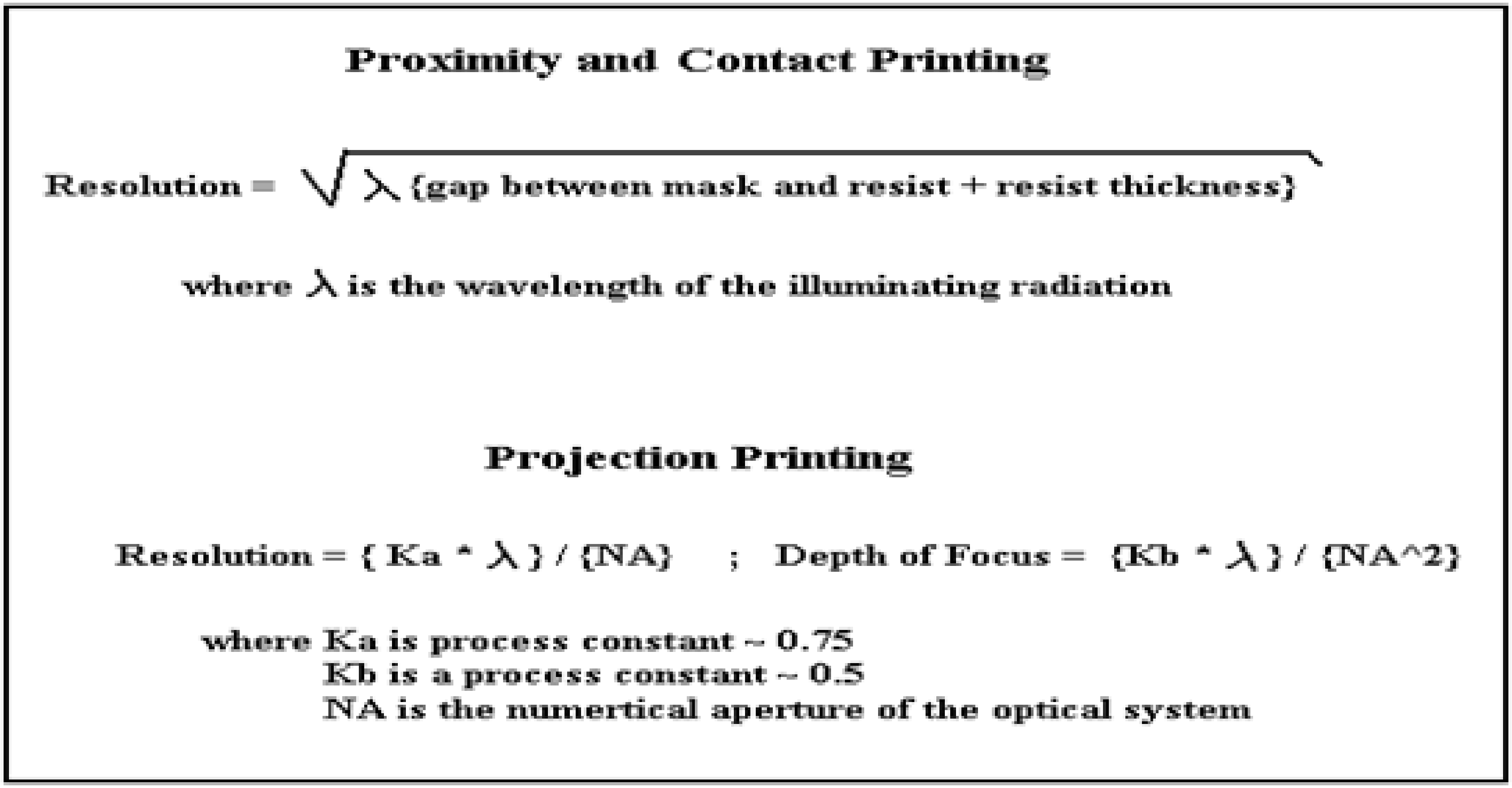
Optical Lithography

- A similar process is performed on the substrate and resist to be patterned for the final structures. For microelectronics, the substrate is silicon or gallium-arsenide.

- For silicon-based MEMS (microelectro mechanical systems), the substrate is also silicon. The mask is then used analagous to a photographic negative and the mask pattern is transferred into the resist carried on the substrate.

- Normally, the mask is held in very close proximity to the substrate and resist in what is termed proximity or shadow printing.

Optical Lithography



Proximity and Contact Printing

$$\text{Resolution} = \sqrt{\lambda\,\{\text{gap between mask and resist} + \text{resist thickness}\}}$$

where λ is the wavelength of the illuminating radiation

Projection Printing

$$\text{Resolution} = \{\,Ka * \lambda\,\} / \{NA\} \quad ; \quad \text{Depth of Focus} = \{Kb * \lambda\,\} / \{NA\hat{}2\}$$

where Ka is process constant ~ 0.75
Kb is a process constant ~ 0.5
NA is the numertical aperture of the optical system

The resolution of the transferred pattern is governed by the diffraction equations for the incident light

LIGA Process

- LIGA is a German acronym for Lithographie, Galvanoformung, Abformung that describes a fabrication technology used to create high-aspect-ratio microstructures.

- LIGA consists of a three min processing steps; lithography, electroplating and molding.

- There are two main LIGA-fabrication technologies, X-Ray LIGA, which uses X-rays produced by a synchrotron to create high-aspect ratio structures, and UV LIGA, a more accessible method which uses ultraviolet light to create structures with relatively low aspect ratios.

LIGA Process

The notable characteristics of X-ray LIGA-fabricated structures include:

- high aspect ratios on the order of 100:1
- The parallel side walls with a flank angle on the order of 89.95°
- smooth side walls with = 10 nm, suitable for optical mirror
- structural heights from tens of micrometers to several millimeters
- structural details on the order of micrometers over distances of centimeters.

LIGA Process

- X-Ray LIGA is a fabrication process in microtechnology that was developed in the early 1980s by a team under the leadership of Erwin Willy Becker and Wolfgang Ehrfeld.
- In the process, an X-ray sensitive polymer photoresist, typically PMMA, bonded to an electrically conductive substrate, is exposed to parallel beams of high-energy X-rays from a synchrotron radiation source through a mask partly covered with a strong X-ray absorbing material.
- The LIGA technique's unique value is the precision obtained by the use of deep X-ray lithography (DXRL). The technique enables microstructures with high aspect ratios and high precision to be fabricated in a variety of materials (metals, plastics, and ceramics). Many of its practitioners and users are associated with or are located close to synchrotron facilities.

LIGA Process

UV LIGA

- UV LIGA utilizes an inexpensive ultraviolet light source, like a mercury lamp, to expose a polymer photo resist, typically SU-8.
- Because heating and transmittance are not an issue in optical masks, a simple chromium mask can be substituted for the technically sophisticated X-ray mask.
- These reductions in complexity make UV LIGA much cheaper and more accessible than its X-ray counterpart.
- However, UV LIGA is not as effective at producing precision molds and is thus used when cost must be kept low and very high aspect ratios are not required.

LIGA Process

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LIGA Process

Process details

LIGA Process

Mask

- X-ray masks are composed of a transparent, low-Z carrier, a patterned high-Z absorber, and a metallic ring for alignment and heat removal.

- Currently, vitreous carbon and graphite are considered the best material, as their use significantly reduces side-wall roughness.

- Silicon, silicon nitride, titanium, and diamond are also in use as carrier substrates but not preferred, as the required thin membranes are comparatively fragile and titanium masks tend to round sharp features due to edge fluorescence.

- Absorbers are gold, nickel, copper, tin, lead, and other X-ray absorbing metals.

Dip pen nanolithography (DPN)

- Dip pen nanolithography is a scanning probe lithography technique where an atomic force microscope (AFM) tip is used to create patterns directly on a range of substances with a variety of inks.

- A common example of this technique is exemplified by the use of alkane thiolates to imprint onto a gold surface. This technique allows surface patterning on scales of under 100 nanometers.

- DPN is the nanotechnology analog of the dip pen (also called the quill pen), where the tip of an atomic force microscope cantilever acts as a "pen," which is coated with a chemical compound or mixture acting as an "ink," and put in contact with a substrate.

Dip pen nanolithography (DPN)

- Deposition material
- Molecular inks

- Molecular inks are typically composed of small molecules that are coated onto a DPN tip and are delivered to the surface through a water meniscus.
- In order to coat the tips, one can either vapor coat the tip or dip the tips into a dilute solution containing the molecular ink. If one dip-coats the tips, the solvent must be removed prior to deposition.

- Water meniscus mediated (exceptions do exist) Nanoscale feature resolution (50 nm to 2000 nm) No multiplexed depositions

Dip pen nanolithography (DPN)

Advantages

Directed Placement - Directly print various materials onto existing nano and microstructures with nanoscale registry

- Direct Write - Maskless creation of arbitrary patterns with feature resolutions from as small as 50 nm and as large as 10 micrometres
- Biocompatible - Subcellular to nanoscale resolution at ambient deposition conditions
- Scalable - Force independent, allowing for parallel depositions

Deep-UV Microlithography

- In recent years, deep-UV exposure tools have been designed and built using KrF excimer laser light sources that have a peak intensity at 248 nm.

- Conventional photoresists are not appropriate for use with these new deep-UV tools due to deficiencies in sensitivity and absorption properties of the materials.

- For most resists, the quantum yield is significantly less than 1, and since the new lithographic tools in general have low brightness sources, high sensitivity resists are required.
- In addition, the absorption of conventional photoresists is too high to allow uniform imaging through practical resist film thicknesses (~1 pm).