Lecture 2

Deposition of Silicon Nitrides

- Silicon nitride is common in the semiconductor industry for the passivation of electronic devices because it forms an excellent protective barrier against the diffusion of water and sodium ions.

- In micromachining, LPCVD silicon nitride films are effective as masks for the selective etching of silicon in alkaline solutions, such as potassium hydroxide.

- Silicon nitride has also been used as a structural material.

Deposition of Silicon Nitrides

- Stoichiometric silicon nitride (Si_3N_4) is deposited at atmospheric pressure by reacting silane (SiH_4) and ammonia (NH_3), or at low pressure by reacting dichlorosilane ($SiCl_2H_2$) and ammonia.

- The deposition temperature for either method is between 700º and 900ºC. Both reactions generate hydrogen as a byproduct, some of which is incorporated in the deposited film.

Deposition of Silicon Nitrides

- CVD and LPCVD silicon nitride films generally exhibit large tensile stresses approaching 1000 MPa.

- However, if LPCVD silicon nitride is deposited at 800º–850ºC and is silicon-rich (an excess of silicon in the film) due to a greatly increased dichlorosilane flow rate, the stress can be below 100 MPa—a level acceptable for most micromachining applications.

Стехиометрия (от др.-греч. (от др.-греч. στοιχεῖον «элемент» + μετρέω «измерять») — раздел химии (от др.-греч. στοιχεῖον «элемент» + μετρέω «измерять») — раздел химии о соотношениях реагентов в химических реакциях.

Позволяет теоретически вычислять необходимые массы и объёмы реагентов.

Deposition of Silicon Nitrides

- For deposition below 400ºC, nonstoichiometric silicon nitride (Si_xN_y) is obtained by reacting silane with ammonia or nitrogen in a PECVD chamber.

- Hydrogen is also a by product of this reaction and is incorporated in elevated concentrations (20%–25%) in the film.

- The refractive index is an indirect measure of the stoichiometry of the silicon nitride film. The refractive index for stoichiometric LPCVD silicon nitride is 2.01 and ranges between 1.8 and 2.5 for PECVD films.

Deposition of Silicon Nitrides

- A high value in the range is indicative of excess silicon, and a low value generally represents an excess of nitrogen.

- One of the key advantages of PECVD nitride is the ability to control stress during deposition.

- Silicon nitride deposited at a plasma excitation frequency of 13.56 MHz exhibits tensile stress of about 400 MPa, whereas a film deposited at a frequency of 50 kHz has a compressive stress of 200 MPa. By alternating frequencies during deposition, one may obtain lower-stress films.


Photoresist Application
(Ontrak)

Spin-On Methods


SRD (Spin, Rinse, Dryer)
(SEZ)

- Spin-on is a process to put down layers of dielectric insulators and organic materials.
- The equipment is simple, requiring a variable-speed spinning table with appropriate safety screens.
- A nozzle dispenses the material as a liquid solution in the center of the wafer. Spinning the substrate at speeds of 500 to 5000 rpm for 30 to 60 seconds spreads the material to a uniform thickness.

Spin-On Methods

- Photoresists and polyimides are common organic materials that can be spun on a wafer with thicknesses typically between 0.5 and 20 μm, though some special-purpose resists such as epoxy-based SU-8 can exceed 200 μm.

- The organic polymer is normally in suspension in a solvent solution; subsequent baking causes the solvent to evaporate, forming a firm film.

Spin-On Methods

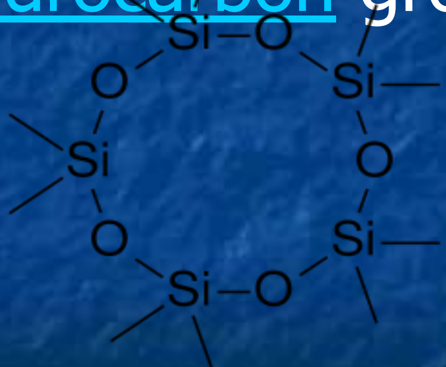
- Thick (5–100 μm) spin-on glass (SOG) has the ability to uniformly coat surfaces and smooth out underlying topographical variations, effectively planarizing surface features.
- Thin (0.1–0.5 μm) SOG was heavily investigated in the integrated circuit industry as an interlayer dielectric between metals for high-speed electrical interconnects; however, its electrical properties are considered poor compared to thermal or CVD silicon oxides.
- Spin-on glass is commercially available in different forms, commonly ***siloxane- or silicate-based***. The latter type allows water absorption into the film, resulting in a higher relative dielectric constant and a tendency to crack.
- After deposition, the layer is typically densified at a temperature between 300º and 500ºC.
- Measured film stress is approximately 200 MPa in tension but decreases substantially with increasing anneal temperatures.

There are two basic types of ***SOG***: siloxane-based organic *SOG* and *silicate-based* inorganic ***SOG***.

Spin on glass (SOG) is a mixture of SiO_2 and dopants (either boron or phosphorous) that is suspended in a solvent solution. The SOG is applied to a clean silicon wafer by spin-coating just like photoresist.

A **siloxane**

- A **siloxane** is any chemical compound composed of units of the form R_2SiSiOSiO, where R is a hydrogenSiO, where R is a hydrogen atom or a hydrocarbon group.



Cyclic siloxanes

- D3: hexamethylcyclotrisiloxane
- D4: octamethylcyclotetrasiloxane
- D5: decamethylcyclopentasiloxane
- D6: dodecamethylcyclohexasiloxane

Linear siloxanes

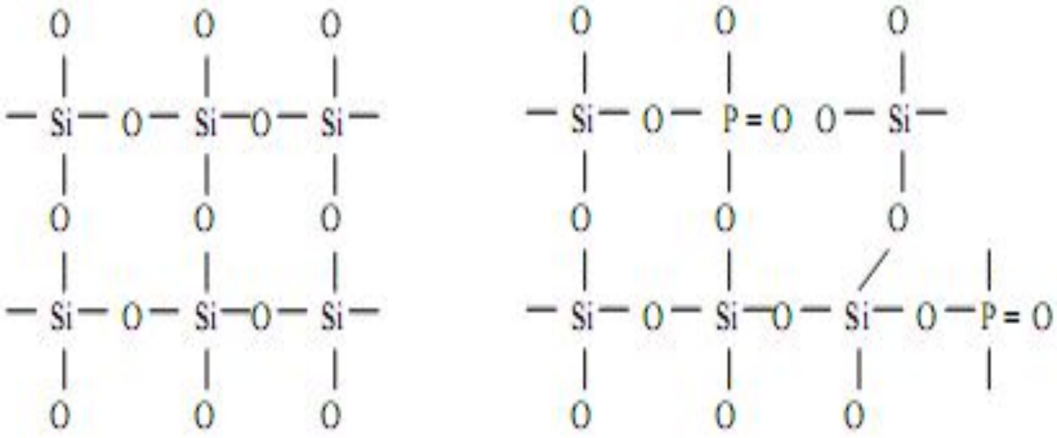
- MM: hexamethyldisiloxane
- MDM: octamethyltrisiloxane
- MD2M: decamethyltetrasiloxane
- MDnM: polydimethylsiloxane

An examples are: [SiO(CH3)2]*n* (polydimethylsiloxane) and [SiO(C6H5)2]*n* (polydiphenylsiloxane).

Silicate-based SOG

1.3.1. Silicate based compounds

The silicate SOG is formed from a condensation reaction of $Si(OH)_4$ by losing water. When the film is fully cured, the film should form a strong Si-O network and contain no -OH but it has fairly significant shrinkage. A rough description of the molecular structure [1] is presented in the following figure:



a) b)

Figure 1-2: a) Silicate SOG and b) P-doped silicate SOG

Lithography

The mask itself consists of a patterned opaque chromium (the most common), emulsion, or iron oxide layer on a transparent fused-quartz or soda-lime glass (**Soda-lime glass**, also called **soda-lime-silica glass**) substrate. The pattern layout is generated using a computer-aided design (CAD) tool and transferred into the opaque layer at a specialized mask-making facility, often by electron-beam or laser-beam writing.

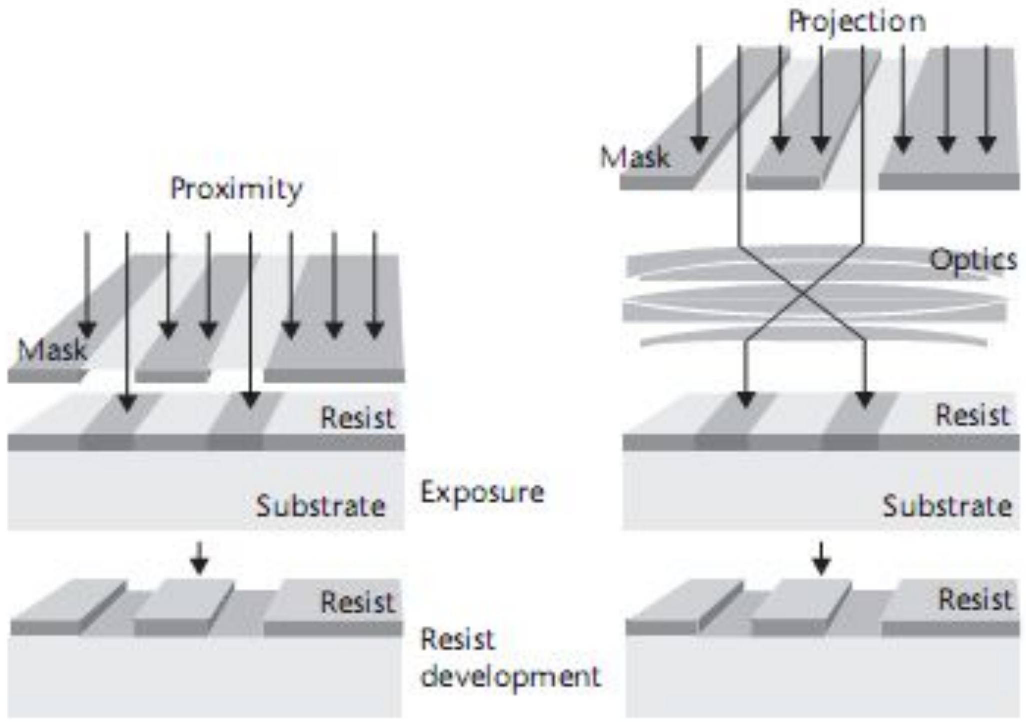


Figure 3.2 An illustration of proximity and projection lithography. In proximity mode, the mask is within 25 to 50 μm of the resist. Fresnel diffraction limits the resolution and minimum feature size to ~ 5 μm. In projection mode, complex optics image the mask onto the resist. The resolution is routinely better than one micrometer. Subsequent development delineates the features in the resist.

Soda-lime glass

- **Soda-lime glass**, also called **soda-lime-silica glass**, is the most prevalent type of glass, used for windowpanes, and glass containers (bottles and jars).

- Soda-lime glass is prepared by melting the raw materialsSoda-lime glass is prepared by melting the raw materials, such as sodium carbonateSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), limeSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomiteSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomite, silicon dioxideSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomite, silicon dioxide (silica), aluminium oxideSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomite, silicon dioxide (silica), aluminium oxide (alumina), and small quantities of fining agents (e.g., sodium sulfateSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomite, silicon dioxide (silica), aluminium oxide (alumina), and small quantities of fining agents (e.g., sodium sulfate, sodium chlorideSoda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomite, silicon dioxide (silica), aluminium oxide (alumina), and small quantities of fining agents (e.g., sodium sulfate, sodium chloride) in a glass furnace at temperatures locally up to 1675 °C

- Soda-lime glass is divided technically into glass used for windows, called *flat glass*, and glass for containers, called *container glass*. The two types differ in the application, production method (float process. The two types differ in the application, production method (float process for windows, blowing and pressing. The two types differ in the application, production method (float process for windows, blowing and pressing for containers), and chemical composition. Float glass has a higher magnesium oxide. The two types differ in the application, production method (float process for windows, blowing and pressing for containers), and chemical composition. Float glass has a higher magnesium oxide and sodium oxide. The two types differ in the application, production method (float process for windows, blowing and pressing for

Coefficient of restitution

Thermal conductivity

Hardness (Mohs scale)
Knoop hardness

Properties	Soda-lime glass for containers	Soda-lime glass for windows
Chemical composition, wt%	74 SiO_2, 13 Na_2O, 10.5 CaO, 1.3 Al_2O_3, 0.3 K_2O, 0.2 SO_3, 0.2 MgO, 0.04 Fe_2O_3, 0.01 TiO_2	73 SiO_2, 14 Na_2O, 9 CaO, 4 MgO, 0.15 Al_2O_3, 0.03 K_2O, 0.02 TiO_2, 0.1 Fe_2O_3
Viscosity $\log(\eta$, dPa·s or Poise$) = A + B / (T$ in °C $- T_o)$	550–1450°C: $A = -2.309$ $B = 3922$ $T_o = 291$	550–1450°C: $A = -2.585$ $B = 4215$ $T_o = 263$
Glass transition temperature, T_g, °C	573	564
Coefficient of thermal expansion, ppm/K, ~100-300°C	9	9.5
Density at 20°C, g/cm^3	2.52	2.53
Refractive index n_D at 20°C	*1.518*	1.520
Dispersion at 20°C, $10^4 \times (n_F - n_C)$	*86.7*	*87.7*
Young's modulus at 20°C, GPa	*72*	*74*
Shear modulus at 20°C, GPa	*29.8*	*29.8*
Liquidus temperature, °C	*1040*	*1000*
Heat capacity at 20°C, J/(mol·K)	*49*	*48*
Surface tension, at ~1300°C, mJ/m^2	315	
Chemical durability, Hydrolytic class, after ISO 719[5]	*3*	*3...4*
Critical stress intensity factor,[6] (K_{IC}), MPa.m$^{0.5}$	*?*	*0.75*

Lime is a general term for calcium is a general term for calcium-containing inorganic materials

- **Lime** is a general term for calcium is a general term for calcium-containing inorganic is a general term for calcium-containing inorganic materials, in which carbonates is a general term for calcium-containing inorganic materials, in which carbonates, oxides is a general term for calcium-containing inorganic materials, in which carbonates, oxides and hydroxides predominate.
- Strictly speaking, lime is calcium oxideStrictly speaking, lime is calcium oxide or calcium hydroxideStrictly speaking, lime is calcium oxide or calcium hydroxide. It is also the name of the natural mineralStrictly speaking, lime is calcium oxide or calcium hydroxide. It is also the name of the natural mineral (native lime) of the CaO composition which occurs as a product of coal seam firesStrictly speaking, lime is calcium oxide or calcium hydroxide. It is also the name of the natural mineral (native lime) of the CaO composition which occurs as a product of coal seam fires and in altered limestoneStrictly speaking, lime is calcium oxide or calcium hydroxide. It is also the name of the natural mineral (native lime) of the CaO composition which occurs as a product of coal seam fires and in altered limestone xenolithsStrictly speaking, lime is calcium oxide or calcium hydroxide. It is also the name of the natural mineral (native lime) of the CaO composition which occurs as a product of coal seam fires and in altered limestone xenoliths involcanic ejecta. The word "lime" originates with its earliest use as building mortar and has the sense of "sticking or adhering."
- These materials are still used in large quantities as building and engineering materials (including limestoneThese materials are still used in large quantities as building and engineering materials (including limestone products, concreteThese materials are still used in large quantities as building and engineering materials (including limestone products, concrete and mortarThese materials are still used in

Lithography

- Positive photoresist is an organic resin material containing a sensitizer. It is spin-coated on the wafer with a typical thickness between 0.5 µm and 10 µm.
- Special types of resists can be spun to thicknesses of over 200 µm, but the large thickness poses significant challenges to exposing and defining features below 25 µm in size.

- The sensitizer prevents the dissolution of unexposed resist during immersion in the developer solution. Exposure to light in the 200- to 450-nm range (ultraviolet to blue) breaks down the sensitizer, causing exposed regions to immediately dissolve in developer solution.

- The exact opposite process happens in negative resists—exposed areas remain and unexposed areas dissolve in the developer.

Lithography

- Resolution, defined as the minimum feature the optical system can resolve, is seldom a limitation for micromachining applications. For proximity systems, it is limited by Fresnel diffraction to a minimum of about 5 µm, and in contact systems, it is approximately 1 to 2 µm.

- For projection systems, it is given by $0.5 \times \lambda / NA$ where λ is the wavelength (~ 400 nm) and NA is the numerical aperture of the optics (~ 0.25 for steppers used in MEMS). Resolution in projection lithography is routinely better than one micrometer.

Lithography

- Depth of focus, however, is amore severe constraint on lithography, especially in light of the need to expose thick resist or accommodate geometrical height variations across the wafer.
- Depth of focus for contact and proximity systems is poor, also limited by Fresnel diffraction.
- In projection systems, the image plane can be moved by adjusting the focus settings, but once it is fixed, the depth of focus about that plane is limited to $\pm 0.5 \times \lambda / NA^2$. Depth of focus is typically limited to few microns.

Lithography

- Projection lithography is clearly a superior approach, but an optical projection system can cost significantly more than a proximity or contact system.
- Long-term cost of ownership plays a critical role in the decision to acquire a particular lithographic tool.
- While resolution of most lithographic systems is not a limitation for MEMS, lithography can be challenging depending on the nature of the application; examples include **exposure of thick resist, topographical height variations, front to back side pattern alignment, and large fields of view.**

Thick Resist

- Patterned thick resist is normally used as a protective masking layer for the etching of deep structures and can also be used as a template for the electroplating of metal microstructures.

- Coating substrates with thick resist is achieved either by multiple spin-coating applications (up to a total of 20 μm) or by spinning special viscous resist solutions at slower speeds (up to 100 μm).

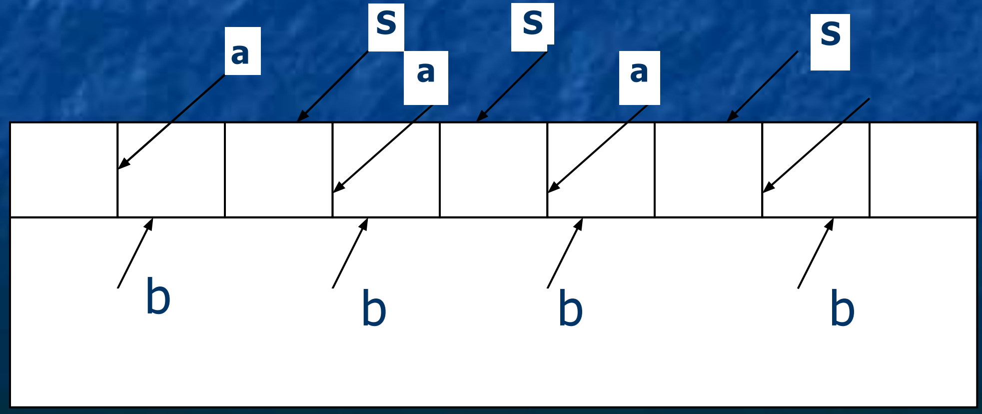
- Maintaining thickness control and uniformity across the wafer becomes difficult with increasing resist thickness.

Thick Resist

- Exposing resist thicker than 5 µm often degrades the minimum resolvable feature size due to the limited depth of focus of the exposure tool—different depths within the resist will be imaged differently. The net result is a sloping (скашивается профиль) of the resist profile in the exposed region.

- As a general guideline, the maximum aspect ratio (ratio of resist thickness to minimum feature dimension) is approximately three—in other words, the minimum achievable feature size (e.g., line width or spacing between lines) is larger than one third of the resist thickness. This limitation may be overcome using special exposure methods, but their value in a manufacturing environment remains questionable.

Aspect ratio = a/b = 3.
Spacing between lines S = b = a/3



Topographical Height Variations

- Changes in topography on the surface of the wafer, such as deep cavities and trenches, are common in MEMS and pose challenges (вызывает проблемы) to both resist spinning and imaging. For cavities deeper than about 10 µm, thinning of the resist at convex corners and accumulation inside the cavity create problems with exposure and with leaving insufficient resist thickness during etches (see Figure 3.3).

- Two recent developments targeting resist coating of severe topography are spray-on resist and electroplated resist.

Topographical Height Variations

- Exposing a pattern on a surface with height variations in excess of 10 μm is also a difficult task because of the limited depth of focus.
- Contact and proximity tools are not suitable for this task unless a significant loss of resolution is tolerable.
- Under certain circumstances where the number of height levels is limited (say, less than three), one may use a projection lithography tool to perform an exposure with a corresponding focus adjustment at each of these height levels. Naturally, this is costly because the number of masks and exposures increases linearly with the number of height levels.

Topographical Height Variations

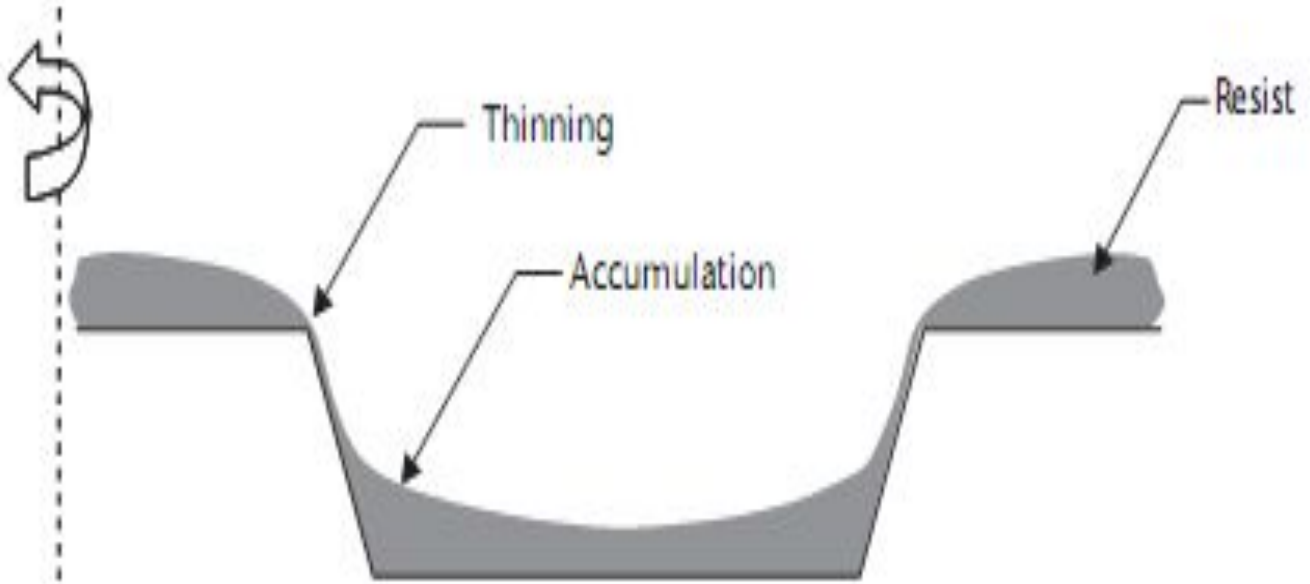


Figure 3.3 Undesirable effects of spin-coating resist on a surface with severe topographical height variations. The resist is thin on corners and accumulates in the cavity.

Double-Sided Lithography

- Often, lithographic patterns on both sides of a wafer need to be aligned with respect to each other with high accuracy.
- For example, the fabrication of a commercial pressure sensor entails forming on the front side of the wafer piezoresistive sense elements that are aligned to the edges of a cavity on the back side of the wafer.
- Different methods of front-to-back side alignment, also known as double-sided alignment, have been incorporated in commercially available tools.
- Wafers polished on both sides should be used to minimize light scattering during lithography.

Double-Sided Lithography

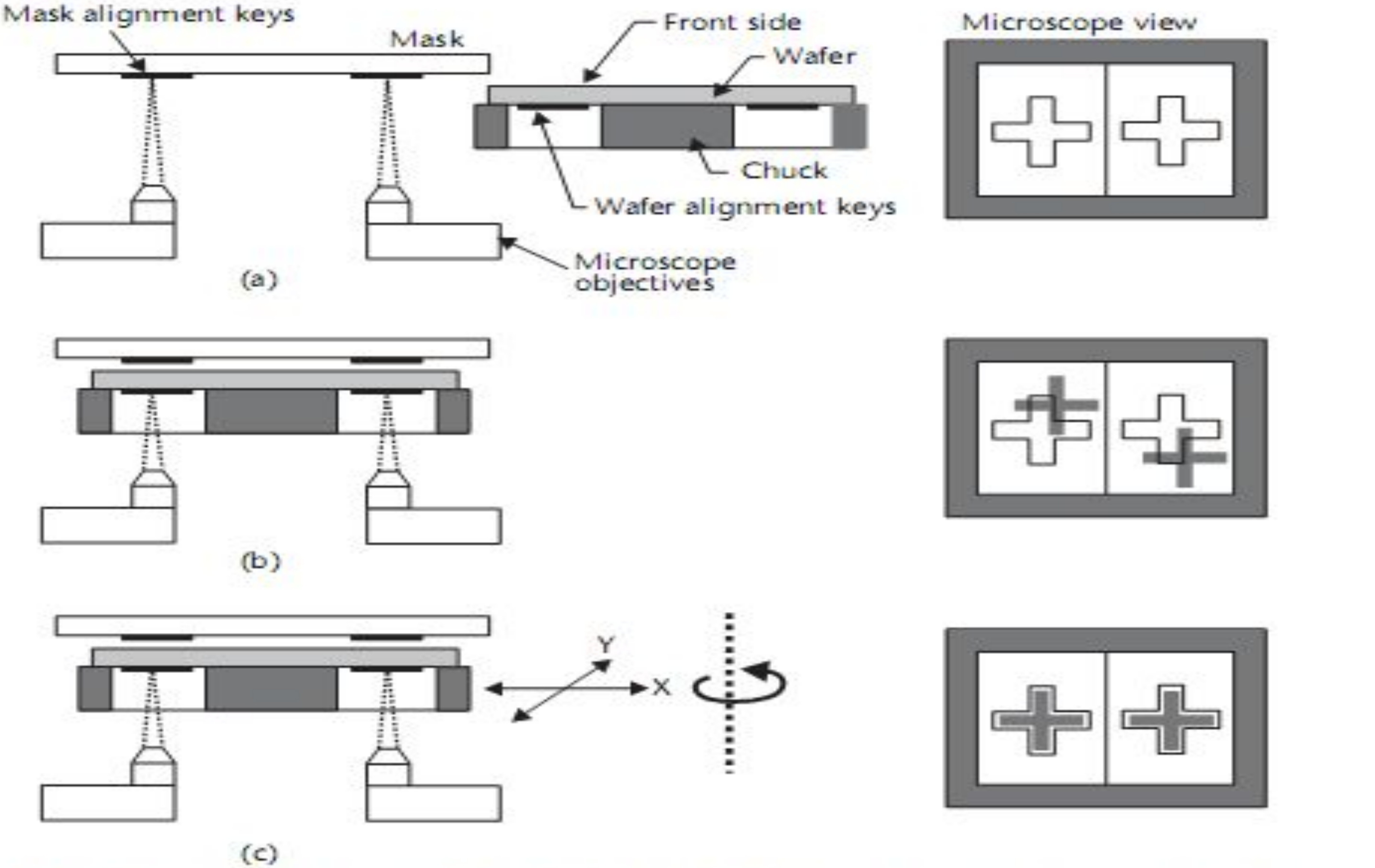


Figure 3.4 Double-sided alignment scheme for the SÜSS MA-6 alignment system: (a) the image of mask alignment marks is electronically stored; (b) the alignment marks on the back side of the wafer are brought in focus; and (c) the position of the wafer is adjusted by translation and rotation to align the marks to the stored image. The right-hand side illustrates the view on the computer screen as the targets are brought into alignment. (*After:* product technical sheet of SÜSS MicroTec of Munich, Germany.)

ЭМ-5086 УСТАНОВКА ДВУСТОРОННЕГО СОВМЕЩЕНИЯ И ЭКСПОНИРОВАНИЯ ЗНАКОВ СОВМЕЩЕНИЯ

- Установка предназначена для нанесения знаков совмещения на обратную сторону пластины, совмещенных со знаками совмещения, сформированными предварительно на её лицевой стороне.

- Работа установки основана на проекционном переносе изображения знака совмещения на обратную сторону пластины. Знаки совмещения на нижней стороне пластины формируются точно напротив знаков совмещения на лицевой стороне пластины.

- Установка применяется в фотолитографических процессах при изготовлении полупроводниковых, гибридных, оптических, оптоэлектронных, МЭМС, МОЭМС и других приборов.

- Применение этой установки позволяет использовать оборудование для односторонней контактной или проекционной фотолитографии для двустороннего технологического процесса вместо использования установок для двусторонней фотолитографии.

Технические характеристики установки

Разрешение проекционной системы, мкм	4
Случайная составляющая погрешности совмещения знаков на двух сторонах подложки, нм	0,3
Размер рабочего поля проекционной системы (диаметр), мм	3
Размер рабочего поля, мм	2,2 х1,7
Диаметр подложек, мм	76,100,150
Толщина подложки, мм	0,2...12,0
Толщина фоторезиста, мм	1±0,1
Дискрет точных линейных перемещений, мкм не более	0,1
Максимальный размер подложек , мм	200
Напряжение сети электропитания, В	230
Частота сети электропитания, Гц	50...60
Потребляемая мощность, не более, кВт	0,3
Габариты установки (ОМУ), мм	400х680х850
Масса установки, не более, кг	250
Площадь, необходимая для размещения установки, м²	2

ЭМ-5026Б УСТАНОВКА ДВУСТОРОННЕГО СОВМЕЩЕНИЯ И ЭКСПОНИРОВАНИЯ

- Установка ЭМ–5026Б выполняет контактным (в зазоре) способом экспонирование верхней стороны полупроводниковой пластины или подложки, совмещая изображение на фотошаблоне с изображением на обратной стороне пластины или подложки.
  При этом дополнительно возможна оценка точности совмещения знаков и изображений (топологий) на двух сторонах пластины (подложки).

Техничесике характеристики установки

Диапазоны рабочих длин волн, нм	225-260; 280-335*; 350-450*
Фотолитографическое разрешение, мкм	0,4...1,0
Производительность (t эксп=5с, без учета t совм), пластин/ч	60
Неравномерность освещенности рабочего поля диаметром 110 мм, %	5
Случайная составляющая погрешности совмещения, мкм при одностороннем по знакам на оратной стороне	 ±0,2 ±1,0
Диаметр обрабатываемых пластин, мм	40*; 50*;60*;76*;100
Размер фотошаблонов, мм	76x76*, 102x102*;127x127
Чувствительность тонкого привода манипулятора совмещения по X, Y, мкм по углу, секунд	 0,01 0,1
Напряжение/частота сети электропитания, В/Гц	230/50...60
Потребляемая мощность, не более, кВт	1
Масса установки, не более, кг	500
Площадь, рекомендуемая для размещения установки, м²	6...8

*Поставляется по специальному заказу.

Large Field of View (Большая область экспонирования)

- The field of view is the extent of the area that is exposed at any one time on the wafer.
  Область проецирования это область, которая экспонируется в любой момент на пластину.

- In proximity and contact lithography, it covers the entire wafer.
  В проекционной и контактной литографии эта область покрывает всю пластину.

Large Field of View (Большая область экспонирования)

- In projection systems, the field of view is often less than $1 \times 1 cm^2$. The entire wafer is exposed by stepping the small field of view across in a two-dimensional array, hence the stepper appellation.

  В проекционной литографии эта область часто меньше чем $1 \times 1 cm^2$. Поэтому вся пластина экспонируется пошагово малыми фрагментами, как двумерный массив.

- In some applications, the device structure may span dimensions exceeding the field of view. A remedy to this is called field stitching, in which two or more different fields are exposed sequentially, with the edges of the fields overlapping.

  В некоторых приборах структура может иметь размеры, превышающие область экспонирования. Для решения этой проблемы делают области сшивания, которые находятся по краям сопрягаемых областей.

Etching

Table 3.1 Wet and Dry Etchants of Thin Metal Films and Dielectric Insulators

	Wet Etchants (Aqueous Solutions)	*Etch Rate (nm/min)*	*Dry Etching Gases (Plasma or Vapor Phase)*	*Etch Rate (nm/min)*
Thermal silicon dioxide	HF	2,300	$CHF_3 + O_2$	50–150
	5 NH_4F:1 HF (buffered HF)	100	$CHF_3 + CF_4$ + He	250–600
			HF vapor (no plasma)	66
LPCVD silicon nitride	Hot H_3PO_4	5	SF_6	150–250
			$CHF_3 + CF_4$ + He	200–600
Aluminum	Warm $H_3PO_4:HNO_3:CH_3COOH$	530	$Cl_2 + SiCl_4$	100–150
	HF	4	$Cl_2 + BCl_3 + CHCl_3$	200–600
Gold	$KI:I_2$	660		
Titanium	$HF:H_2O_2$	110–880	SF_6	100–150
Tungsten	Warm H_2O_2	150	SF_6	300–400
	$K_3Fe(CN)_6:KOH:KH_2PO_4$	34		
Chromium	$Ce(NH_4)_2(NO_3)_6:CH_3COOH$	93	Cl_2	5
Photoresist	Hot $H_2SO_4:H_2O_2$	>100,000	O_2	350
	CH_3COOH_3 (acetone)	>100,000		

Оборудование фирмы SCR (Чехия) участка химического травления кремниевых пластин

Isotropic Wet Etching

- The most common group of silicon isotropic wet etchants is HNA, also known as *iso etch* and *poly etch* because of its use in the early days of the integrated circuit industry as an etchant for polysilicon. It is a mixture of hydrofluoric (HF), nitric (HNO_3), and acetic (CH_3COOH) acids, although water may replace the acetic acid.

- In the chemical reaction, the nitric acid oxidizes silicon, which is then etched by the hydrofluoric acid. The etch rate of silicon can vary from 0.1 to over 100 μm/min depending on the proportion of the acids in the mixture. Etch uniformity is normally difficult to control but is improved by stirring.

Isotropic and Anisotropic Etching

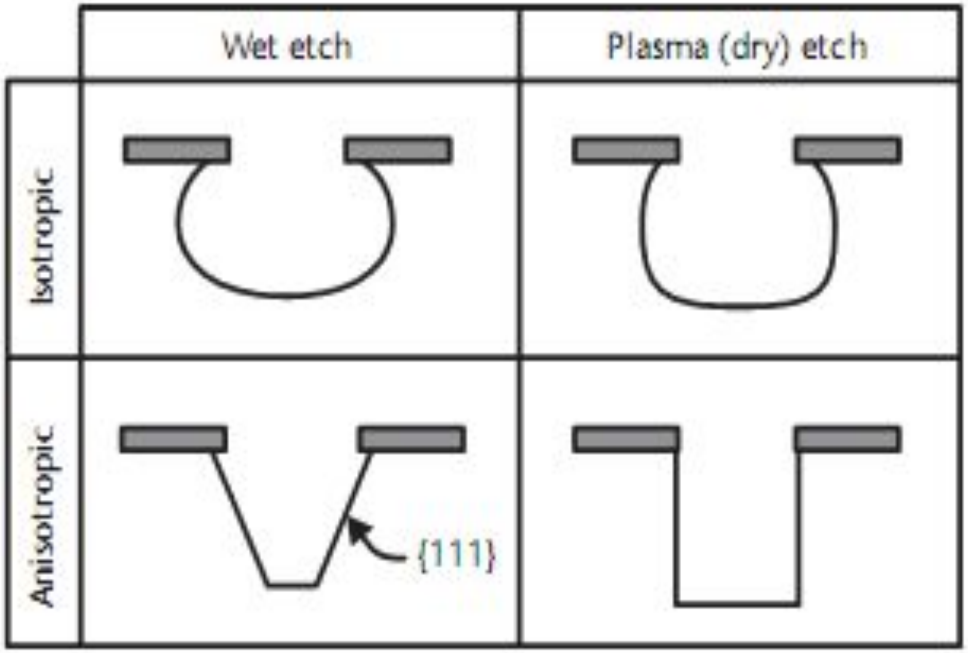


Figure 3.5 Schematic illustration of cross-sectional trench profiles resulting from four different types of etch methods.

Anisotropic wet etchants

- Anisotropic wet etchants are also known as orientation-dependent etchants (ODEs) because their etch rates depend on the crystallographic direction.

- The list of anisotropic wet etchants includes the hydroxides of alkali metals (e.g., NaOH, KOH, CsOH), simple and quaternary ammonium hydroxides (e.g., NH_4OH, $N(CH_3)_4OH$), and ethylenediamine mixed with pyrochatechol (EDP) in water.

- The solutions are typically heated to 70º–100ºC. A comparison of various silicon etchants is given in Table 3.2.

Anisotropic Wet Etching

Table 3.2 Liquid, Plasma, and Gas Phase Etchants of Silicon

	$HF{:}HNO_3{:}$ CH_3COOH	KOH	EDP	$N(CH_3)_4OH$ (TMAH)	SF_6	SF_6/C_4F_8 (DRIE)	XeF_2
Etch type	Wet	Wet	Wet	Wet	Plasma	Plasma	Vapor
Typical formulation	250 ml HF, 500 ml HNO_3, 800 ml CH_3COOH	40 to 50 wt%	750 ml Ethylenediamine, 120g Pyrochatechol, 100 ml water	20 to 25 wt%			Room-temp. vapor pressure
Anisotropic	No	Yes	Yes	Yes	Varies	Yes	No
Temperature	25°C	70°–90°C	115°C	90°C	0°–100°C	20°–80°C	20°C
Etch rate (μm/min)	1 to 20	0.5 to 3	0.75	0.5 to 1.5	0.1 to 0.5	1 to 15	0.1 to 10
{111}/{100} Selectivity	None	100:1	35:1	50:1	None	None	None
Nitride etch (nm/min)	Low	1	0.1	0.1	200	200	12
SiO_2 Etch (nm/min)	10–30	10	0.2	0.1	10	10	0
p^{++} Etch stop	No	Yes	Yes	Yes	No	No	No

(*After:* [3, 6].)

KOH is by far the most common ODE

- Etch rates are typically given in the [100] direction, corresponding to the etch front being the (100) plane.
- The {110} planes are etched in KOH about twice as rapidly as {100} planes.
- While {111} planes are etched at a rate about 100 times slower than for {100} planes.

Oblique [эблик] = скошенный

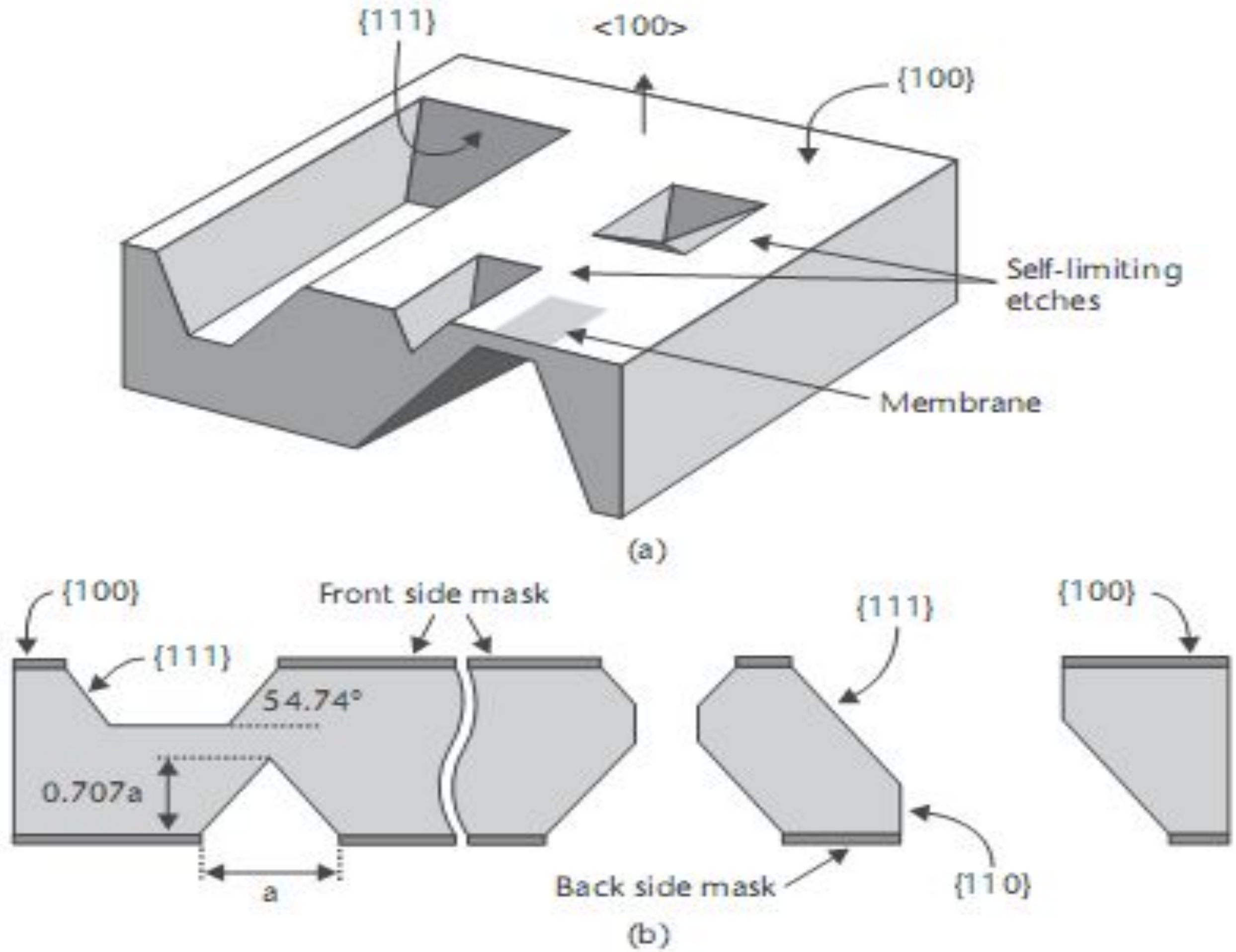


Figure 3.6 Illustration of the anisotropic etching of cavities in {100}-oriented silicon: (a) cavities, self-limiting pyramidal and V-shaped pits, and thin membranes; and (b) etching from both sides of the wafer can yield a multitude of different shapes including hourglass-shaped and oblique holes. When the vertically moving etch fronts from both sides meet, a sharp corner is formed. Lateral etching then occurs, with fast-etching planes such as {110} and {411} being revealed.