microfabrication techniques have roots in the sta ndard fabrication methods developed for the semico nductor industry [8. 1?3] . some of these techniqu es are common between the micro/nano and very larg e-scale integration (VLSI) microchip fabrication disciplines . lithography is the technique used t o transfer a computer-generated pattern onto a sub strate (silicon, glass, GaAs, etc.) this pattern i s then used to etch an underlying thin film (oxide , nitride, etc

silicon s ubstrate spin photoresist Soft bake Alig n the mask Expose the wafer Develop the resist Har d bake End of litho graphy Fig. 8.1 Lithography pr ocess flow Part A 8.1Basic Microfabrication Techni ques 233 1. Contact 2. Proximity 3. Projection Alt hough contact printing gives better resolution com - pared with the proximity technique, the constant contact of the mask with the photoreasist reduces the process yield and can damage the

silicon oxidation is a process used to obtain a th in film of SiO_2 with excellent quality (very low density of defects) and thickness homogeneity . a layer of about 20 (native oxide) is enough to pas sivate the surface and prevent further oxydation .

the process is typically carried out at temperatu res in the range of 900?1200C in the pres- ence of O_2(dry oxyation) or H_2O + carrier gas .

the introduction of certain impurities in a semico n- ductor can change its electrical, chemical, and even mechanical properties . in micro-/nanofabric ation technologies doping has additional applicati ons such as the forma-tion of piezoresistors for m echanical transducers or the creation of etch stop -layers . ion implantation allows more precise con trol of the dose and the impurity profile (the con centration versus depth) .

the most common CVD processes in mi- crofabricatio n are low-pressure CVD (LPCVD)a n d plasma-enhan ced (PECVD) large numbers of wafers can be proces sed simultaneously and the ma- terial is deposited on both sides . the process temperature depends o n the material to be de- posited, but generally is in the range 550?900C . as in oxidation, high tem peratures and contamination is- sues

silicon-on-sapphire substrates and some het- erost ructures are fabricated in this way . most common in microfabrication is the growth of silicon on an other silicon substrate . the most common for sili con is thermal chemical vapor deposition or vapor-phase epitaxy (VPE). the latter typically uses m olecular beams from thermally evap-orated elementa l sources aiming at the substrate in an ultrahigh-vacuum chamber .

inert ions bombarding the target are produced in d irect-current (DC)o r RF plasma . evaporation and sputtering systems are often able to deposit more than one material simultane- ously or sequentially . tension in evaporated or sputtered layers is ty pically tensile . thickness beyond 2 m is rarely d eposited with these processes . electrodeposition is a process typi- cally used to obtain thick meta l structures .

Pulsed laser and atomic layer deposition have attr acted a considerable amount of attention re- centl y . these two techniques offer several unique adva ntages compared with other thin-film deposition . a typical PLD deposition setup method that is part icularly useful for next-generation nanoscale devi ce fabrication . the main advantages of the PLD ar e its simplicity and ability to deposit complex ma terials with preserved stoichiometry . other depos ited materials include transition metals (Cu, Co, Fe, and Ni), metal oxide

wet etching and silicon nitride are the most common masking ma- terials for the wet oxide etch . silicon dioxide is commonly etched in dilute (140?200 C) phosphoric acid with sili- con oxide as the masking material . etch rate of 1000 /min in HF (BHF :H F+NH 4F) is not very common in micro/nanofabrication .

Isotropic etching of silicon using HF/HNO 3/CH3COOH dates back to the 1950s . the etch mechanism for this combination has been elucidated and is as follows: HNO 3is used to oxidize the sili- con, which is then dissolved away in the HF . for short etch times, silicon dioxide can be used as the masking material; however, one needs to use sili nitride if a longer etch time is

silicon wafer under etch consists of an n-epi region on a p-type substrate . a reverse-biased p?n junction (electrochem- ical etch stop) is formed and etching is stopped . one must take into account the finite etch rate of the masking materials . the three basic dry etch techniques are plasma based

. they have several advantages when compared with wet etchants .

ion milling is a purely physical process which use s accelerated inert ions (e.g., Ar+) striking per- pendicular to the surface to remove the material (p104?103Torr) the main charac- teristics of this technique are very low etch rates (in the order of a few nm /min) and poor selectivity (close to 1:1 for most materials); hence it is generally used t o etch very thin

silicon-silicon bonding is one of the most importa nt fab-rication techniques in microsystem technolo gy . silicon?silicon fusion (or silicon direct bon ding) and silicon?glass electrostatic (or anodic) bonding are used in micromechanical devices and si licon-on-insulator (SOI) substrates . the bonding procedure is as follows: the silicon or oxide-coat ed silicon wafers are first thoroughly cleaned (ac tivated) in HF .

silicon fusion bonding is another major substrate joining technique . a high-temperature (800?1200C) anneal is usually re- quired . the bond can be ob served visu- ally as a dark-grayish front which ex

pands across the wafer . silicon?silicon anodic bo
nding using sputtered or evaporated glass interlay
er is also possible . in eutectic bonding process,
 gold-coated silicon wafers are bonded

eutectic bonding can be accomplished at low temper
atures but achieving uniformity over large areas h
as proven to be challenging . glass frit can also
be used as an interlayer in sub- strate bonding .
a thin layer of glass is deposited and preglazed a
nd the sandwich is heated to above the glass melti
ng temperature . the dimensional spectrum of the m
icrostructures that can be fabricated using these
tech-niques spans from 1 mm to 1 m .

a robot based station can take over precise proces
sing and assembly tasks . a microassembly station
must be able to automatically accomplish the follo
wing steps with its microrobots . this step can al
so be automated in a versatile microa . station .
the topic "flexible micromanipulation systems" has
 become of interest, especially for microsystem pr
oduction . it is a topic of interest for . microsy
stems, especially in biomedical research and eye a
nd plastic surgery .

the availability of highly precise assembly proces ses will make it easier to realize operable micros ystems . micromanipulation is a common practice in medicine and biological research . many microrobo ts can be active at the same time in a multifuncti onal manipulation desktop station . the use of sev eral flexible robots allows the operator to perfor m manipulations in different work areas . if the a ssem bly tasks are more complex, the robot's comma nds are passed along to an input unit .

nanorobot systems carry out the manipulation tasks in close cooperation . the robot size is comparab le to that of the manipulated object . in general manipulations vary from an application to another, the following 4 operational sequences are always taking place: grip, transport, position, release, adjust, fix in place and processing steps like cut ting, soldering, gluing, removal of impurities, et c. the realization of this concept, which is based on human behavior, is in the di stant future.