Epitaxial growth of thin films

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Abstract

The term 'epitaxial' is applied to a film grown on top of the crystalline substrate in ordered fashion that atomic arrangement of the film accepts crystallographic structure of the substrate. Epitaxial growth is one of the most important techniques to fabricate various 'state of the art' electronic and optical devices. Modern devices require very sophisticated structure, which are composed of thin layers with various compositions. Quality, performance and lifetime of these devices are determined by the purity, structural perfection and homogeneity of the epitaxial layers. Epitaxial crystal growth resulting in epitaxial layer perfection, surface flatness and interface abruptness depend on number of factors like: the epitaxial layer growth method, the interfacial energy between substrate and epitaxial film, as well as the growth parameters – thermodynamic driving force, substrate and layer misfit, substrate misorientation, growth temperature, etc… Recently epitaxial growth is also used for fabrication of semiconductor quantum structures like quantum dots giving highly perfect structures with high density. In this report the aspect determining the epitaxial growth mode, epitaxial layer growth techniques and additional focusing on SiC epitaxial growth is discussed.

1. Epitaxial growth modes

The occurrence of the epitaxial growth modes depends on various parameters of which the most important are the thermodynamic driving force and the misfit between substrate and layer. The growth mode characterizes the nucleation and growth process. There is a direct correspondence between the growth mode and the film morphology, which gives the structural properties such as perfection, flatness and interface abruptness of the layers. It is determined by the kinetics of the transport and diffusion processes on the surface. Different atomistic processes may occur on the surface during film growth: deposition, diffusion on terraces, nucleation on islands, nucleation on second-layer island, diffusion to a lower terrace, attachment to an island, diffusion along a step edge, detachment from an island, diffusion of dimmer (see Figure 1).

Experimentally, the distinction between three classical growth modes is well known: Frank-van der Merwe (FV), Volmer-Weber (VW) and Stranski-Krastonov (SK). In addition to the three well-known epitaxial growth modes mentioned above there are four distinct growth modes: step flow mode, columnar growth, step bunching, screw-island growth (see Figure 2) [1, 2].

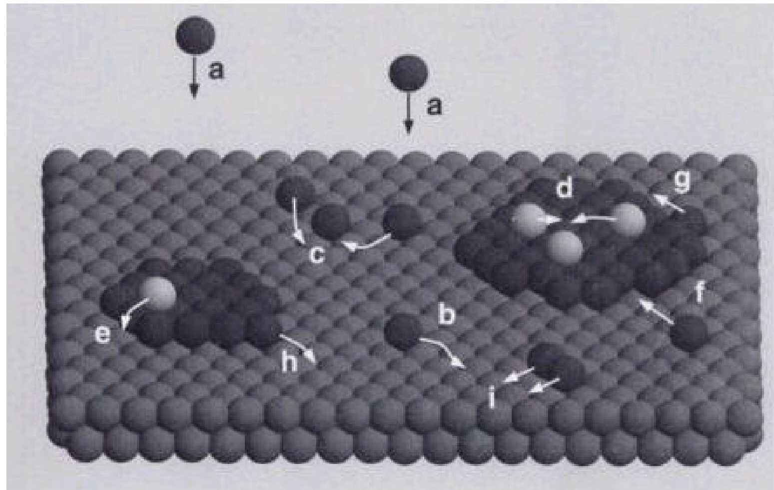

Figure 1: Atomistic processes during the growth: a) deposition, b) diffusion on terraces, c) nucleation on islands, d) nucleation on second-layer island, e) diffusion to a lower terrace, f) attachment to an island, g) diffusion along a step edge, h) detachment from an island, i) diffusion of dimmer.

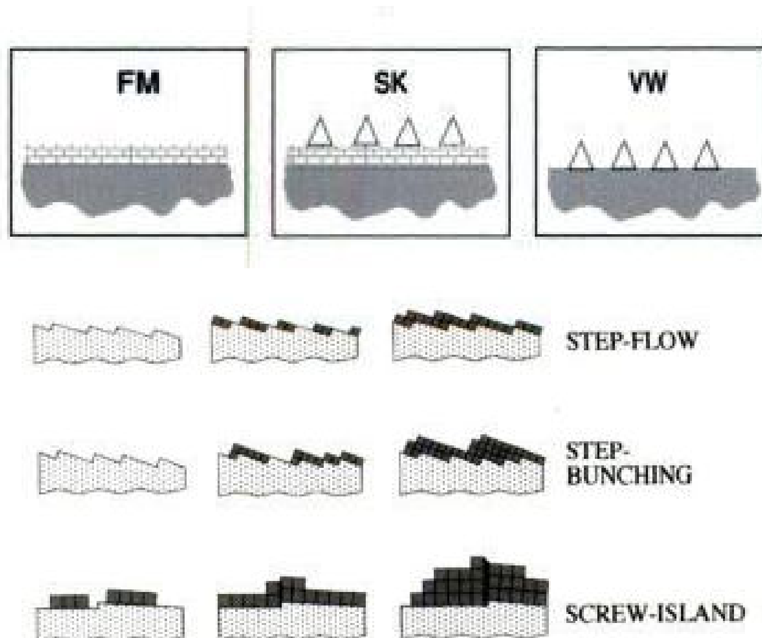

Figure 2: Three successive growth stages, of the six growth modes. The upper three classical growth modes, the lower four additional growth modes.

Frank-van der Merwe (FV) growth mode

During FV or layer-by-layer growth mode a new layer is nucleated only after completion of the layer below, this growth occurs over long distances in ideal case. However crystals are not perfect and contain defects like dislocation that acts as a 'sink' for growth species. Normally there are continues step source like screw dislocations or other defects, so FV growth mode works continuously and it can spread growth steps over macroscopic distances. The optimum layer homogeneity can be achieved by one dimensional movement of steps in FV mode initiated by a precise controlled small angle substrate misorientation.

Volmer-Weber (VW) growth mode

A VW growth mode consists in first phase of large number of surface nuclei and in second phase of their spreading. Thus VW growth often results in a high mosaicity of the material inside the layer. Usually continues growth of the layer, after initial VW growth, occurs by columnar growth, but in the case of 3C-SiC on Si a VW growth mode results in growth of layers that are not columnar using right conditions.

Stranski-Krastonov (SK) growth mode

SK mode is considered as intermediate between the FV and VW growth modes, and it is caused by significant lattice misfit from film and substrate. The lattice mismatch between the substrate and the film creates a build-in strain as a consequence of the increasing elastic energy with increasing layer thickness. The first deposited layer is atomically smooth (FV growth mode), compressively strained layer up to a certain thickness called critical thickness. When the deposition time is enough exceeding the critical thickness – phase transition to islands rapidly takes place (VW growth mode), because the nonuniform strain field can reduce the strain energy by an island array, compared with a uniform flat film, resulting in the SK growth mechanism.

Step flow growth mode

Step flow mode is clearly distinct from layer-by layer growth in FV mode. Unidirectional step flow is induced by substrate missorientation (off cut angle). This trick is often used to avoid island formation, their coalescence and following columnar growth in epitaxy from the vapor phase.

Step bunching growth mode

Step bunching is observed when a high density of steps moves whit large step velocities over the growth surface. By fluctuations, higher steps catch up with lower steps and then move together as double, triple…. Or in general as macro steps that can exceed thickness of thousands of monosteps. The microsteps cause different incorporation rates of impurities and dopands due to locally varying growth rate

Spiral-island growth mode

Coalescence of larger number of initial growth islands may lead to screw dislocations due to the layer structure resulting in spiral-island growth mode.

2. Control of growth modes

There are two main types of epitaxy – homoepitaxy and heteroepitaxy. Homoepitaxy is when the same material (or polytype) as the substrate is grown for example: Si on Si, 4H-SiC on 4H-SiC. Heteroepitaxy is when a different material (or polytype) from the substrate is grown for example: GaN on sapphire, 3C-SiC on 6H-SiC. In heteroepitaxy the lattice mismatch between substrate and film and the supersaturation, plays a key role on growth mode and this is demonstrated in Figure 3.

This layer-by-layer growth mode FV requires the zero misfit as indicated in the Figure 3. Large lattice misfit normally induces VW mode except for large interface energies between substrate and film, which will cause SK mode. If structural

perfect layer are required, either homoepitaxy or substrate with zero misfit are needed. On another hand the misorientation of the substrate provides steps on surface depending on the angle and direction of misorientation. The density of the steps can be made so high and interstep distance so small that VW or SK modes can be suppressed. The layers growth in the step flow mode have relatively high crystal perfection because defects due to coalescence are prevented [3, 4].

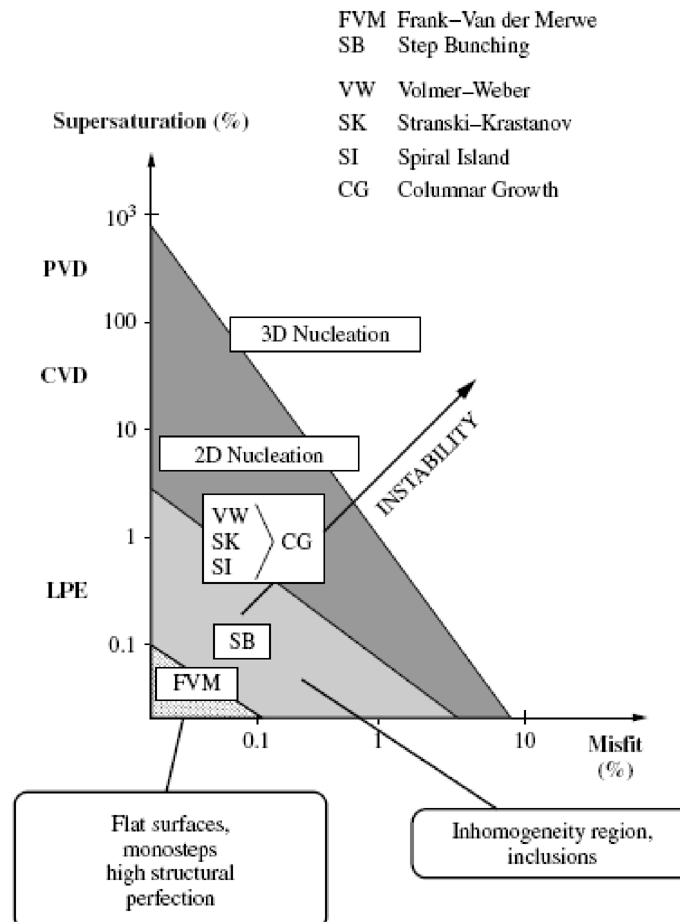

Figure 3. The effect of both supersaturation and misfit on the nucleation modes.

The best structural perfection can be achieved by FV growth mode, which requires substrate of very low misfit and very low supersaturation. The FV growth mode can be achieved by near equilibrium process like LPE (LPE will be described later).

3. SiC Polytype control

The best eptaxial layer qualities are achieved by using homoepitaxy, because of the compatibility of grown material with substrate. However not all materials substrates are commercially available. For example the only commercially available SiC substrates are of the 4H and 6H polytypes. So if one wants to grow 4H or 6H-SiC, there are no big problems to do homoepitaxy, however to grow 3C-SiC heteroepitaxy has to be applied.

Using heteroepitaxy one has to care about lattice misfit, temperature expansion coefficient and etc. - not all substrates can be used.

It is known that SiC exists in different polytypes, there are more then 200 of them. Most stable are 4H-, 6H- and 3C-SiC (Figure 4). When growing homoepitaxy or heteroepitaxy one should care about polytype inclusions, which are very common. One could think about temperature dependence for polytype stability, but from Figure 5 [5] it is clear, that two or more polytypes can grow at the same temperature, so other polytype control methods has to be applied. For homoepitaxy of hexagonal polytypes, one solution is to increase surface mobility of the adatoms by higher temperature, but usually this is not preferable, because of technical problems. The most popular thing in SiC homoepitaxy is to cut substrate off-axis to create steps (Figure 6).

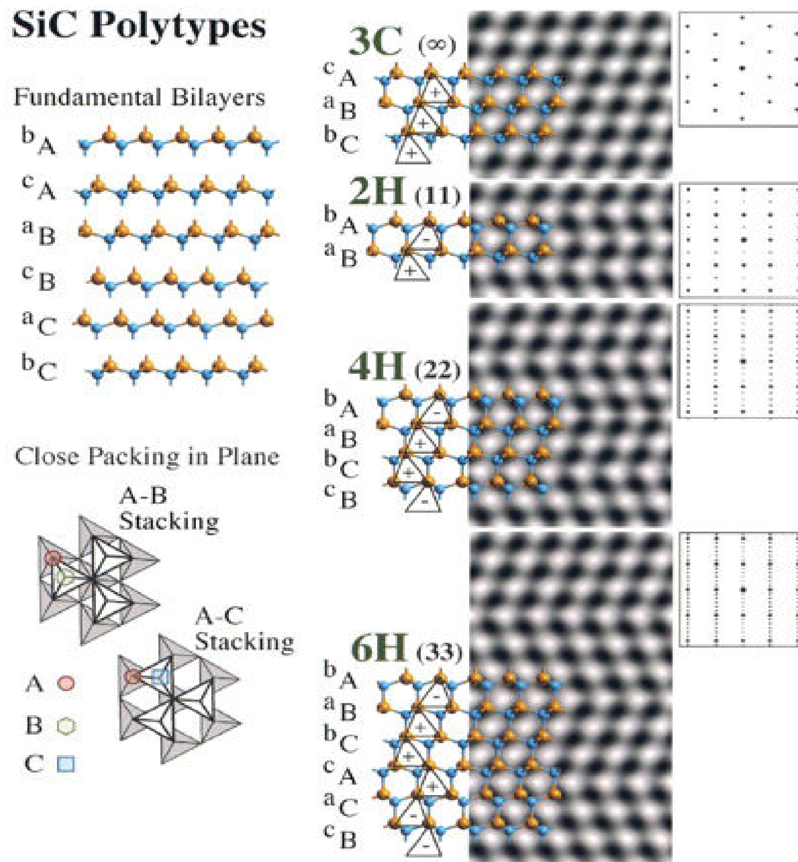

Figure 4. Silicon carbide polytype structures. Polytypes of SiC are formed by those periodic stacking sequences of bilayers that produce tetrahedral sheets. Atomic models of the six unique (fundamental) bilayers (bA, cA, aB, cB, aC, and bC) of SiC (top left) based on three principle close packed planes (A, B, and C) (lower left) are shown. Blue atoms represent C and orange atoms represent Si. The two basic stacking arrangements, A-B and A-C, that form planes of vertex-sharing parallel and antiparallel tetrahedra, respectively, are shown (lower left). Atomic models of the four simplest, 3C/(∞), 2H/(11), 4H/(22), and 6H/(33), polytypes are shown superimposed on calculated HR-TEM lattice images produced using defocus conditions that reproduce the symmetry of the projected lattice (center column). Schematic illustrations of diffraction patterns (including forbidden reflections in some cases) are also shown (right column) [6].

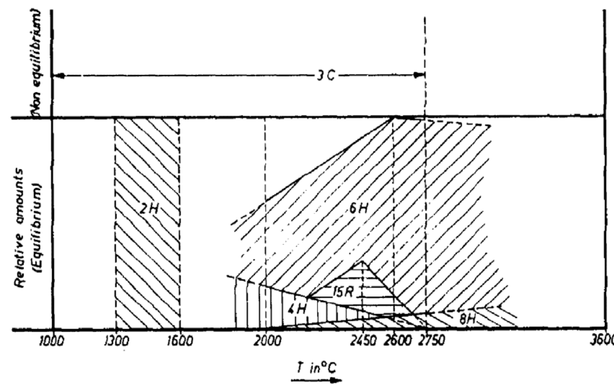

Figure 5. Relation between different polytypes of SiC and the temperature of occurrence.

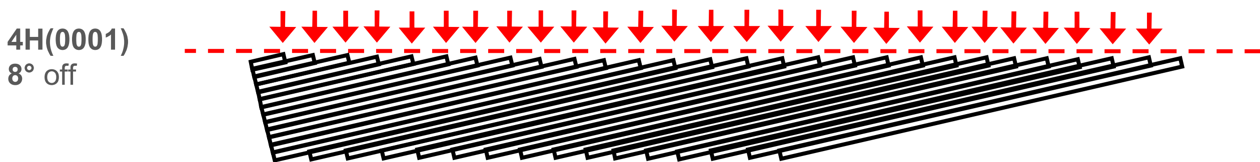

Figure 6. SiC crystal cut off-axis.

However for heteroepitaxy the off-axis cut is not preferable. So on axis substrates are used especially for 3C-SiC growth on 4H or 6H-SiC, because then substrate polytype is not reproduced and 3C-SiC nucleates in 2D islands.

Cubic SiC (3C-SiC)

3C-SiC is the only one cubic structure among all 200 SiC polytypes. 3C-SiC is also known as β-SiC while hexagonal structures, e.g. 4H-SiC and 6H-SiC are known as α-SiC. From Table 1 in comparison to other SiC polytypes, 3C-SiC has the highest value in electron mobility, breakdown electric field and saturated electron drift velocity. These great properties make 3C-SiC to be the most desirable SiC polytype for electronic devices fabrication. When growing 3C-SiC on hexagonal substrates like 4H-SiC or 6H-SiC, because of difference in bandgap energy between these polytypes emerges possibilities to create heteroepitaxial junctions from SiC. These junctions would combine the superb properties or SiC both electrically and physically.

Table 1. Comparison of SiC properties with other semiconductors [7].

Materials	Lattice constant (Å)	Bandgap energy E_g (eV)	Electron mobility μ (cm^2/Vs)	Breakdown electric field E_B (10^6V/cm)	Saturated electron drift velocity V_{sat} (10^7cm/s)	Thermal conductivity α (W/cm K)	Dielectric constant ε_r	Maximum operating temperature (°C)
Si	5.43	1.1	1350	0.3	1.0	1.5	11.8	300
GaAs	5.65	1.4	8500	0.4	2.0	0.5	12.8	460
GaN	a = 3.189 c = 5.185	3.4	2000	5.0	2.5	1.4		
AlN	a = 3.11 c = 4.98	6.1	1100	11.7	1.8	2.5	8.7	
Diamond	3.56	5.45	1900	5.6	2.7	20.0	5.5	1100
3C-SiC	4.36	2.23	1000	4.0	2.7	3.2	9.75	1240
4H-SiC	a = 3.08 c = 10.08	3.2	a = 720 c = 650	2.0	2.0	4.5	10.0	1240
6H-SiC	a = 3.08 c = 15.11	3.0	a = 370 c = 50	2.4	2.0	4.5	9.7	1240

One problem of 3C-SiC growth is that so far we do not have 3C-SiC free-standing substrates available. Therefore, growth of 3C-SiC must be performed on other substrates. The most researchers use Si as a substrate. However, 20% of lattice

and 8% of thermal expansion coefficient mismatch between 3C-SiC and Si [7] causes a lot defects occurrence. High density of misfit dislocations, stacking faults, microtwins and anti-phase boundaries has a serious effect on quality and purity of grown crystals.

Double positioning boundaries (DBPs) of 3C-SiC

DBPs is a special defect for 3C-SiC growth on hexagonal substrate which comes from the two possible orientations of the cubic 3C-SiC axis on the hexagonal α-SiC basis [8]. Because 3C-SiC has two different orders in stacking sequence either ABCABC… or ACBACB… Normally in on-axis substrate, these two stacking sequences can be formed on the substrate in alter positions (see Figure 7). When the nucleated domains expand via 2D-nucleation mechanism, these two domains cannot blend together according to a different stacking order. The boundaries of these two domains are so-called "Double Positioning Boundaries". DBPs can be observed as 60 degrees angle difference of triangular defects according to the crystal structure. These defects will limit the expanding of domains and the size of single crystal growth.

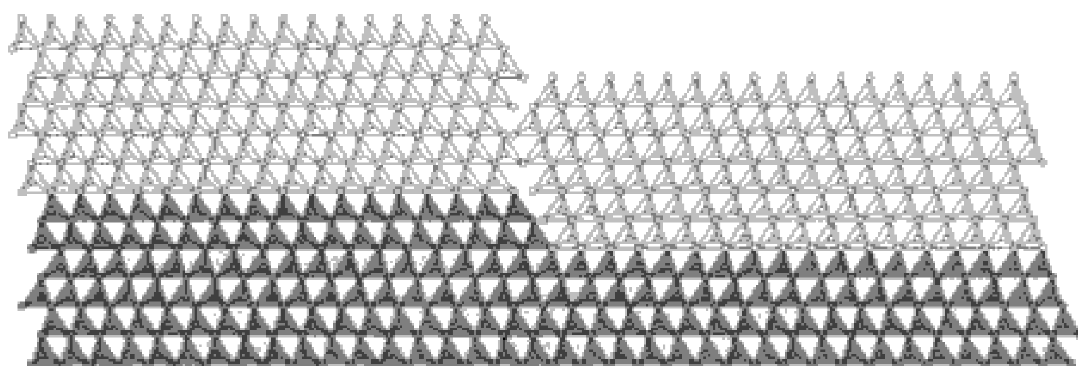

Figure 7. Nucleation of 3C-SiC epilayer on 4H-SiC substrate and formation of double positioning boundary. 4H-SiC surface with a two bilayer step is shown in darker color.

4. TECHNIQUES FOR EPITAXY

The techniques of epitaxy can be classified according to the phase (till ex: liquid (solution), or vapor) of material use to form the epitaxial layer. Growth techniques: liquid phase epitaxy (LPE), physical vapor deposition (PVD) and molecular beam epitxay (MBE).

4.1 Molecular beam epitaxy (MBE)

Molecular beam epitaxy is a technique for epitaxial growth via the interaction of one or several molecular or atomic beams that occurs on a surface of a heated crystalline substrate. In Figure 8 scheme of a typical MBE system is shown. The substrate, on witch the heterostructure to be grown, is placed on a sample holder which is heated to the necessary temperature and, when needed, continuously rotated to improve the growth homogeneity [9].

The growth in the MBE requires ultra high-vacuum (UHV), typically 10^{-6} – 10^{-4} mbar during growth. After outgasing under such a high vacuum, O_2, CO_2, H_2O, and N_2 contamination on the growing surface can be neglected. The typical growth conditions make possible to reduce the rate down to nm/sec, so that precise control of the growth thickness is possible – this is a great advantage [10].

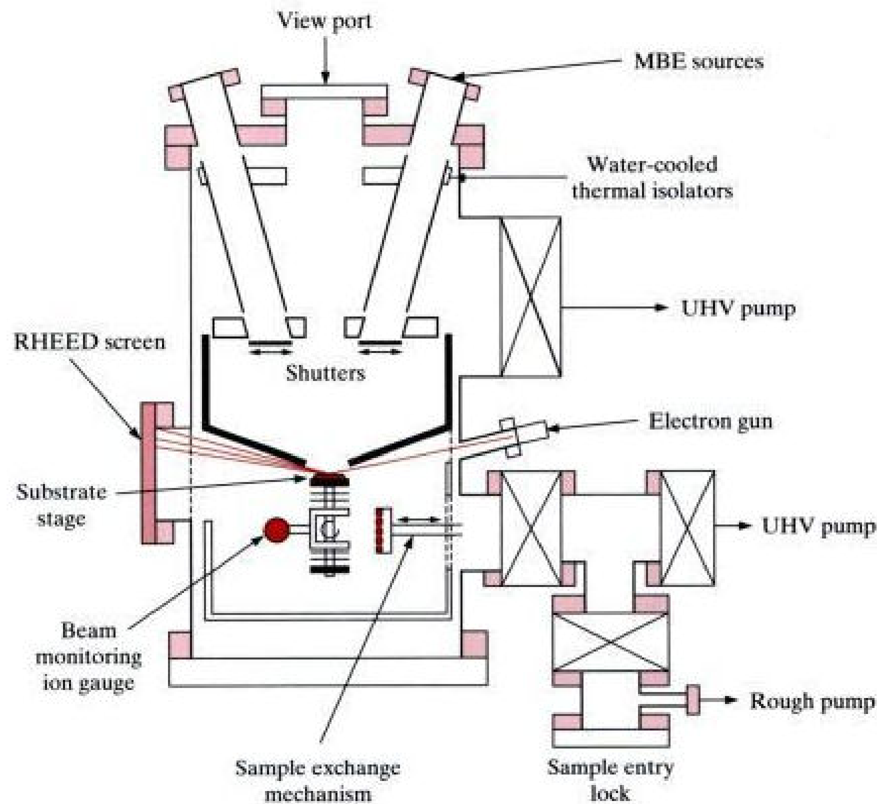

Figure 8: Sketch of MBE system.

Although simple in principle MBE is not simple in practice. The substrates are carefully prepared and cleaned with extreme purity if their properties are not to be spoil by contamination. This in turn requires pure starting materials, only ultra pure sources are used. The background pressure in the evaporator must be kept low to reduce contamination. The flux of effusion cell must be uniform across the substrate. The reaction chamber is evacuated to $<10^{-8}$ mbar and the walls of the chamber cooled with liquid nitrogen. Even so the highest mobility layers are only grown after an extended run when the machinary has completely cleaned itself.

An important feature of MBE is that it takes place in UHV, which means that some diagnostic techniques can be used to monitor the growth. The most common is reflected high-energy electron diffraction (RHEED). The surface changes in a periodic way as each monolayer is grown and this can be seen in the intensity and pattern of the RHEED signal. Thus growth can be controlled precisely at the monolayer level.

During the MBE process, growth can be monitored in situ by a number of methods: RHEED, low energy electron diffraction (LEED); auger electron spectroscopy (AES), modulated beam mass spectrometry (MBMS).

Advantages of MBE: (1) excellent interface and surface morphology, (2) abrupt hetero-junctions, (3) growth of complex heterostructures with many different layers, (4) in-situ characterization techniques (RHEED), (5) high purity starting materials, easy chemistry, (6) safer for some material growth than CVD (As and Se exceptions) (7) low growth temperature.

Disadvantages of MBE: (1) graded interfaces, (2) structures with many different compositions (only 4 metal sources in most machines), (3) run-to-run reproducibility, (4) low growth rates, (5) high temperatures are hardly reached, (6) very difficult and costly to implement and maintain.

Growth of SiC by MBE

Although growth with MBE has a lot of advantages, like: growth of atomically abrupt interfaces, heteropolytype engineering (for example 4H/3C/4H heterostructure) and in-situ characterization, for growth of SiC it is almost not used. Firstly because of high costs. Secondly because of source material availability, Si source is not a problem, but C is not so easy, graphite can be used, but high temperature cells are needed, C_{60} doesn't require high temperature cells, but material is expensive.
And for usage of gaseous precursors a lot of technical problems arises like: keeping ultra high vacuum and high temperatures are needed (>1200 ^{0}C), which is hard to implement in MBE. Also grown layers have high background doping levels and polytype inclusion is a serious problem [9, 10].

4. 2 Liquid phase epitaxy (LPE)

The process known as LPE is a technique for the deposition of the epitaxial layers from supersatured solution. The chosen solvent has generally low melting point and low vapor pressure.

LPE method is mainly used for the growth of compound semiconductors. Very thin, uniform and high quality layers can be produced. Typical example of LPE method is given by the growth of III-V compounds. In this case, the process can be described as follows: a melt of pure gallium exposed to a GaAs wafer will dissolve some of the solid to produce a dilute solution of group V element. Cooling this solution to induce a slight supersaturation, and bringing a substrate into the contact with the melt surface, will result in the growth of a layer of GaAs all over the substrate surface. At conditions that are close to the equilibrium, deposition of the semiconductor crystal on the substrate is slowly and uniform. The equilibrium conditions depend very much on the temperature and on the concentration of the dissolved semiconductor in the melt. The thickness of the epitaxial layer is controlled by the contact time between substrate and solution, the cooling rate, rate of diffusion of the slowest component elements etc…

The major advantage of the LPE is that the growth temperature can be well below the melting point of the compound semiconductor which is being decomposed. Furthermore, equipment is simple and inexpensive, also non-hazardous.

Key problem in the production of the epilayer is that the composition of relatively small volumes of each melt will rapidly change as crystal growth proceeds. LPE is too simple to grow more complicated nanostructures, because of the difficult thickness and composition control, etc…

Figure 9 shows sketches of three kinds of LPE growth process: a tipping arrangement, slightly more complicated sliding substrate holder and sandwich arrangement.

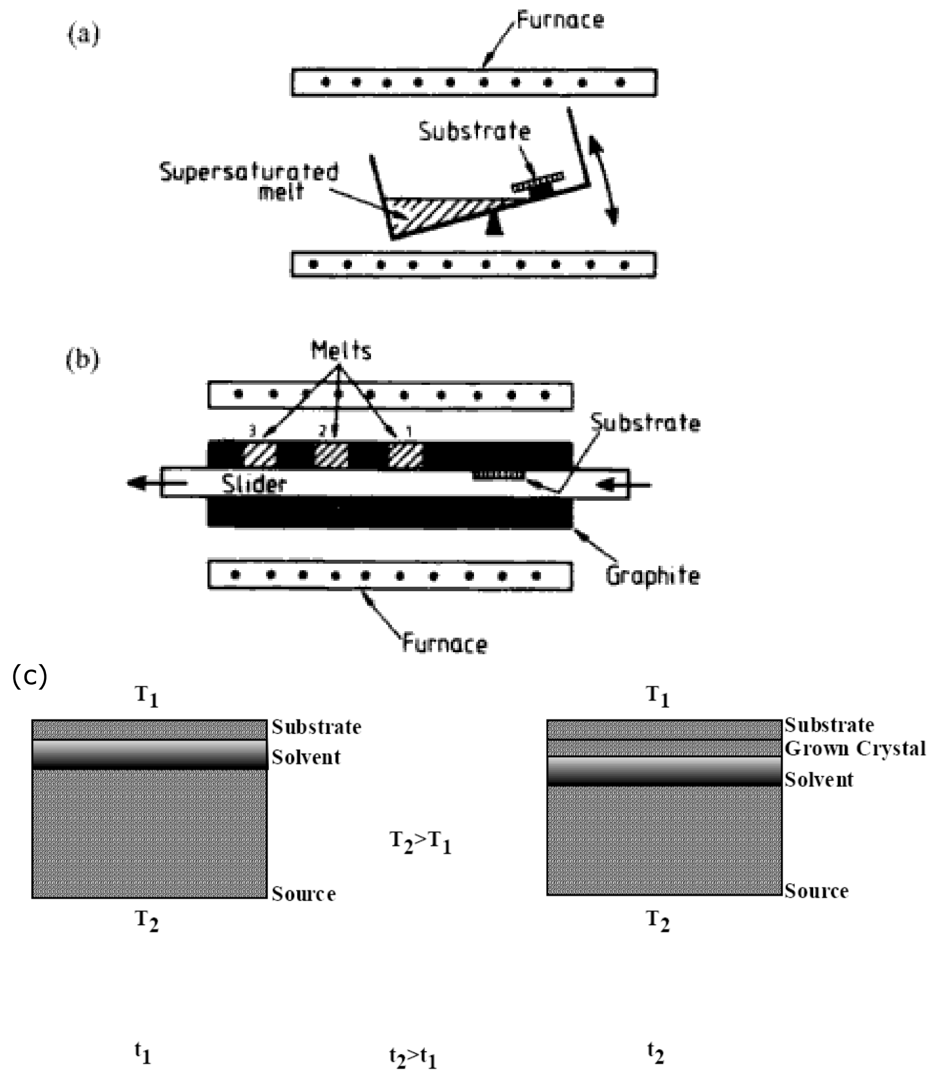

Figure 9. Sketch of two kinds of LPE process: (a) a tipping arrangement; (b) a sliding arrangementl; (c) sandwich arrangement.

LPE of SiC

SiC does not form a stoichiometric liquid phase at normal conditions. The Si-C phase diagram is shown in Figure 10. Instead the material decomposes to vapor at 2830 °C. Silicon carbide can be grown from the liquid phase by using a non-stoichiometric melt. The natural choice as base for the solution would be Si since this is a constituent of SiC and high-purity Si is commercially available.

The growth rates using silicon as a solvent are not high since the solubility of C in Si is very low at temperatures less than 2000 °C. By introducing a transition metal to the silicon melt the solubility of carbon is increased. An example is given by using Si-Sc melts for which the liquid phase epitaxy of SiC has successfully demonstrated good influence on the growth rate and on the structural properties (crystallinity and surface morphology) of the SiC epitaxial layers. The tipping and sliding arrangement, as shown in figure 9, are not used for SiC epitaxy by LPE because of the high reactivity of the melt with the crucible. Most of the time, a dipping or sandwich arrangement is preferred.

One critical issue in SiC bulk crystal growth is the generation of micropipes. Micropipes existing in the substrates can be closed during liquid phase epitaxial growth [11].

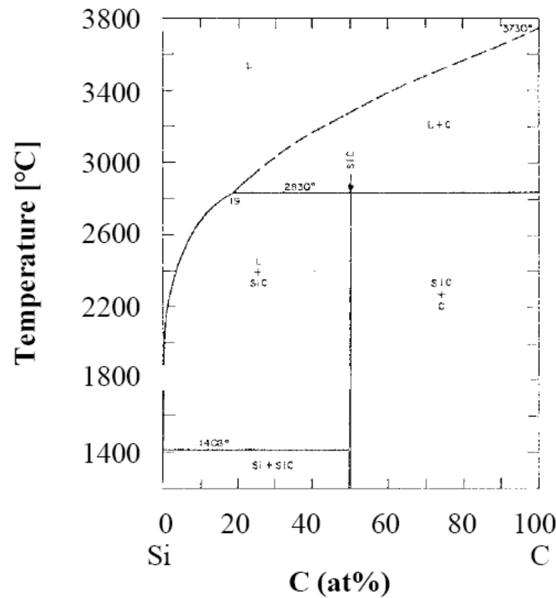

Figure 10. Si-C phase diagram.

4.3 Vapor-liquid-solid (VLS) method

The vapor-liquid-solid (VLS) method has recently been re-examined to produce one dimensional structures (whiskers) for nano-physics technology or other applications [12]. The VLS mechanism has been also developed for growth of SiC epitaxial layers. Some of the basic mechanisms involved in the VLS method are similar to LPE. In case of LPE, carbon is supplied by the graphite container, a solid SiC source in direct contact with the solution or initial dissolution of the substrate while in the VLS method the carbon is provided through the reaction of a carbon containing gas phase with silicon containing liquid phase. The difference to "conventional" LPE growth conditions is that VLS growth may be performed even at a negative temperature gradient, i.e. the temperature is higher at the substrate than in the liquid or the top of the solution, and the requirements on the temperature gradient are not as strict.

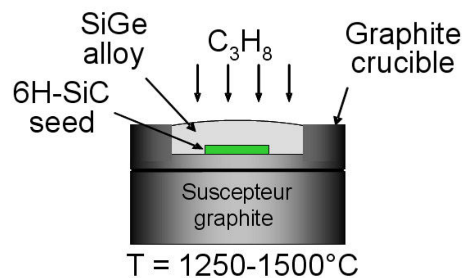

Figure 11. Sketch of VLS growth system.

The carbon containing gas is cracked above the free liquid surface (vapor – liquid interface), Figure 11 may illustrate the technique assuming a carbon gas support in the vapor phase. Then the dissolved carbon will migrate to the substrate driven by the carbon activity gradient between the top and the bottom of the liquid (at the liquid - solid interface). Studies using propane as carbon supply for SiC VLS growth with Al-Si liquid demonstrates that the growth rate is linearly dependent

to the propane flux. At high propane flux a SiC crust on the droplet is formed and blocks further growth. Depending on the technological implementation, e.g. see [13], the liquid may be removed by suction and the appearance of macroscopical steps on the surfaces becomes less pronounced. One of the main issues in this method is to have a uniform silicon based liquid phase on the SiC seed. The use of too thin a liquid interphase, e.g. to decrease the diffusion length within the silicon solvent to increase the growth rate, may result in the partial lack of coverage of the substrate by the solution and thus non uniform growth occurs. The SiC growth rate by VLS is more pronounced at the edge of the liquid phase while the polytype of the substrate may not be replicated. Similar to LPE, the growth rate becomes low using pure silicon due to the low solubility of carbon in silicon. To promote the carbon solubility and reduce the growth temperature, various alloys based on silicon may be used. The silicon based alloys extensively studied for SiC VLS growth are Al, Fe, Ni, and Co [14]. The composition of the solution is a crucial parameter utilizing metallic elements, which dissolve a high concentration of carbon. A solvent with an excess of metal atoms in comparison to the silicon content provides a pronounced dissolution of the substrate. Conditions favorable for growth are reached by increasing the silicon content.

4.4 Physical vapor deposition (PVD)

Sublimation epitaxy is a novel growth method by which thick SiC layers can be grown with a high growth rate. The principal technology used is similar as the one in sublimation bulk growth of SiC through which commercialized substrates are produced. Any upgrading in reactor size for sublimation epitaxy can easily follow the ones in bulk growth technology.

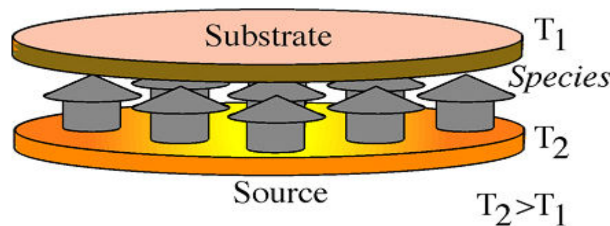

Figure 12. Sublimation of a SiC source and transport of vapor species to the growing surface during sublimation epitaxy

The process is based on sublimation of a SiC source and transport of vapor species to the growing surface (Figure 12), i.e. the physical principle is the same as in bulk growth [15]. The difference in sublimation epitaxy is the short distance between source and growing surface, which diminish disturbances caused by the vapor species transport interaction with the graphite wall of the growth container, and that growth proceeds in vacuum which yields fast vapor species transport. Due to this, growth can be performed at low temperature (typically about 1800 ^{o}C) and still have a high rate (~100 μm/h). Commercial SiC epilayers are grown by the CVD method, which has a growth rate, around 5 μm/h and thick layer epitaxy is difficult due to instabilities during long growth durations. However tremendous improvements in growth rates obtained by CVD, either using chlorinated precursors or with the standard SiH_4-C_3H_8 system done in the past few years. By CVD very pure layers can be grown.

In addition, in sublimation epitaxy a solid SiC source is used instead of conventional use of SiC powder. Thus disturbances caused by the irregular surface of the powder are avoided. Commonly, in SiC epitaxy there is a need to pre-treat the substrate surface prior to growth. In sublimation epitaxy this is

inherent in the growth process by a surface removal through initial sublimation of the substrate surface at the temperature ramping to the growth temperature. These properties enable homoepitaxial growth of 6H and 4H-SiC layers with smooth surfaces, even in very thick material.

No hazardous gases are used, which makes the technology safe. No clean room class area is needed. The loading procedure is simple, no attachment is needed, because substrate is placed on the graphite spacer and heating to growth can take place almost immediately after loading. No expensive parts with protective coating (as needed in CVD) are used, the growth containers do not degrade even after hundreds of growth runs, and the basic technology is simple. These issues make the system cost low and running cost will mainly depend on the substrate cost. A limitation is that low doped (10^{15} cm^{-3} or less) growth needs to be developed.

4. 5 Chemical vapor deposition (CVD)

Chemical vapor deposition (CVD) technique offers a number of advantages such as good film uniformity, compatibility, conformal growth with very good step coverage, high deposition rates and scalability from laboratory to production systems [16].

CVD is a method for depositing films of various materials, and involves the thermally induced reaction of a molecule on a heated surface. This technology is now an essential factor in the manufacture of semiconductors.

A special case of CVD is the Metal Organic CVD (MOCVD), the difference between MOCVD and CVD is that in the MOCVD case one or more of the precursors are supplied as an organic-metal such as TMGa or TMAl.

Principle of CVD process

The principle of CVD is rather simple. Atoms that we would like to be in the crystal are brought in the vapour phase under the form of organic/inorganic molecules and passed over a hot semiconductor wafer. The heat breaks up the molecules and deposits the desired atoms on the surface, layer by layer if proper conditions are used. By varying the composition of the gas, we can change the properties of the crystal at an almost atomic scale. One can grow high quality semiconductor layers (as thin as a millionth of a millimetre) and the crystal structure of these layers is perfectly aligned with that of the substrate. The undesired radicals formed during the molecules cracking are dragged away by the main stream of the vector gas. A schematic representation of the generalized key steps is presented in Figure 13. Principle of a CVD process: 1. feed of the molecules in the gas-phase to the substrate; 2. supply of energy (thermal, plasma, light) for cracking the molecules; 3. deposition of the material, evacuation of the molecule fragments in the gas-phase [17].

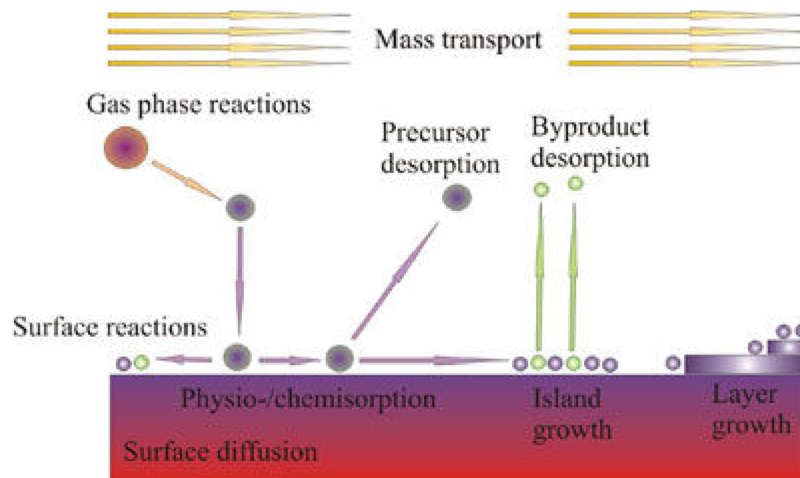

Figure 13. Principle of a CVD process.

Deposition kinetics

Both gas-phase transport rates and surface reaction rates are important for CVD and either of them can be rate limiting. If the surface is at a sufficiently high temperature, the reaction can potentially proceed more rapidly than the rate at which reactant gases are supplied to the substrate. This results in a mass-transport-limited process. If the mass transport is sufficiently fast, the deposition rate may then be limited by the rate at which the reactants are fed to the chamber. The general trend of the growth rate (in logarithmic form) as a function of the inverse of the temperature is depicted in Figure 14. Feed rate limited deposition usually provides a rate with weak temperature dependence. Increasing the surface temperature does not result in an increase in the rate, which can be no faster than the rate of delivery of the precursor into the reactor.

For diffusion-limited deposition, the rate dependence is far weaker than the one observed for surface-reaction-limited deposition and is nearly flat when plotted on a logarithmic scale.

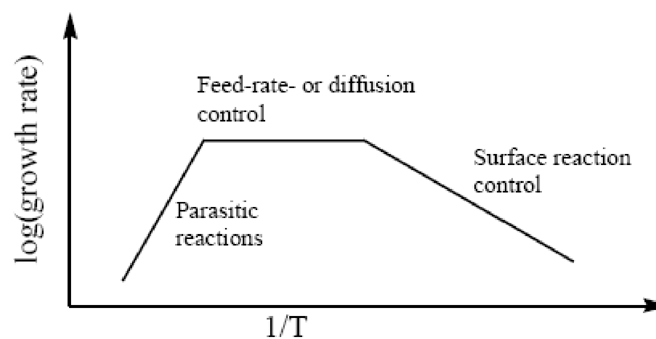

Figure 14. Temperature dependence of the deposition rate.

Finally, as the substrate temperature is increased, gas-phase particle formation may occur, which depletes the reactant concentration, therefore reducing the rate. Alternatively, in this high temperature regime, the precursor rapidly desorbs from the surface before any reaction can occur. Another factor affecting the deposition rate is, of course, the reactant concentration: as this increases, the deposition rate increases up to a certain point only. Indeed, if the precursors concentration is too high, then homogeneous nucleation in the gas phase may occur so that it can limit the supply at the growing surface.

CVD setup

Usually CVD setup consist of 5 parts: precursor sources, a gas handling system, a reaction chamber, a heated wafer holder and a vacuum pump. The apparatus of the simplified MOCVD is illustrated in Figure 15. The source of the different vapours is connected to the reactor furnace through mass flow controllers and vents. A continuous flow at controlled pressure is maintained in the right composition. The working pressure in the reactor could be from atmospheric pressure down to few mbars.

Figure 15 show a highly simplified scheme of this apparatus. The substrate sit on the heated block in a chamber through which different gases are passed using hydrogen as carrier gas; the composition of the gas phase can be varied rapidly to control the composition of the material grown.

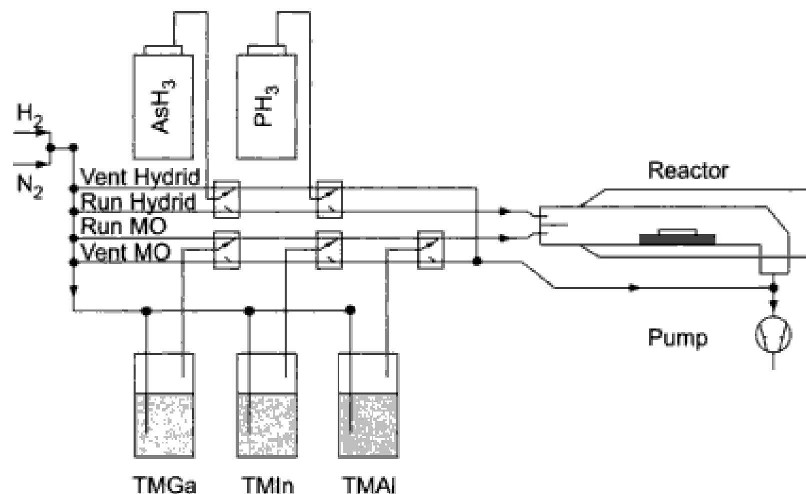

Figure 15. Schematic view of MOCVD apparatus.

Advantages of CVD: (1) excellent interface and surface morphology, (2) abrupt or graded hetero-junctions, (3) growth of complex heterostructures with many different layers, (4) growth on patterned substrates, (5) multiple wafer scale-up, (6) high purity of the layers.

Disadvantages of CVD: (1) safety –large quantities of serious toxic or flammable gases (AsH_3, SiH_4…), (2) almost no possibility of in situ monitoring, (3) not the best technique for some specific material (lack of adequate precursors or of not suited growth conditions).

Also, it should be mentioned that the apparatus of CVD is much simpler than that required for MBE, although a major practical problem is the handling of the highly toxic gases (witch raises the overall cost to a similar level to MBE). The main use of CVD in industry is for Si technology; also CVD is extensively used for growing III-V compounds. MBE is mainly useful for research lab experiments because less efficient for mass production. CVD is useful for lab experiments and for mass production as well.

5. Conclusions

Epitaxial growth is one of the most important techniques to fabricate various 'state of the art' electronic and optical devices. This was the driving force to write about epitaxial growth. Here we have discussed major epitaxial techniques for SiC growth, mentioned epitaxial growth modes and control of their growth, SiC

polytypism and usual methods for controlling polytype growth. Major techniques for SiC growth like LPE (VLS) and VPE (SE and CVD) are also mentioned.

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