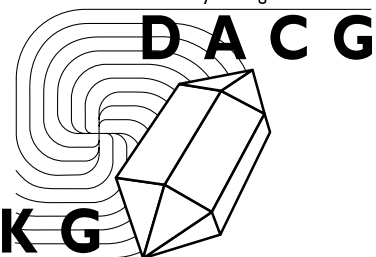


FACET

dutch association for crystal growth



i n f o r m a t i e b l a d v a n d e

nederlandse vereniging voor kristalgroei

mei 2000
nummer 1

FACET

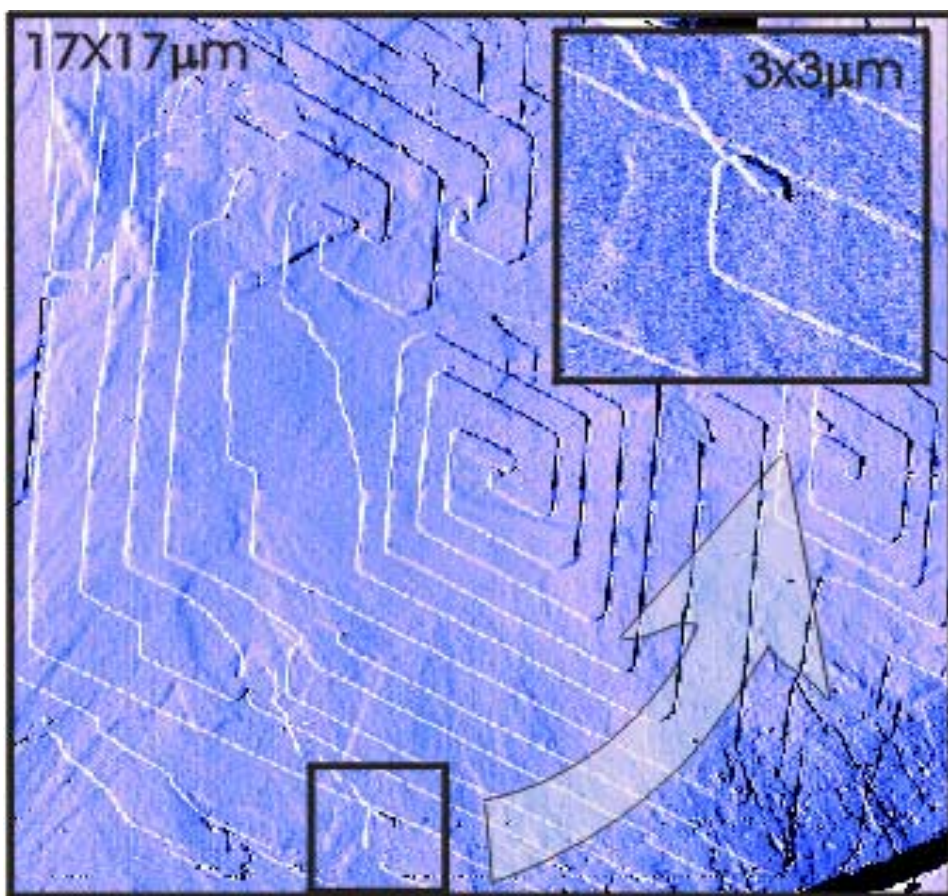
informatieblad van de NVKG
sectie van de KNCV en de NNV

redactie

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Bestuur **NVKG**

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Dr. ir. H.J.M. Kramer	secretaris
Dr. R. Geertman	penningmeester
Dr. H.H.C. de Moor	lid
Dr. A. van Geelen	lid
Prof. dr. J. van der Eerden	lid
Prof. dr. E. Vlieg	lid

Omslagfoto

De voorkant laat een ex situ Atomic Force Microscope (AFM) opname zien van het (001) oppervlak van een uit de oplossing gegroeid n-C₄₀H₈₂ kristal. Een n-C₄₀H₈₂ paraffine molecuul is een onvertakte 5 nm lange alkaanketen met 40 C atomen. In de ruimtengroep van deze kristallen, Pca₂₁, staan de moleculen alle parallel aan elkaar; loodrecht op het (001) vlak. De ruitvorm van de enkel- en tweevoudige spiralen getoond op het (001) vlak weerspiegelt de ruimtengroep-symmetrie. De tredes op het oppervlak zijn alle mono-moleculair. Behalve de rechte spiraal-tredes die tijdens de groei zijn ontstaan, zijn er ook onregelmatige tredes te zien. Deze onregelmatige tredes kruisen de spiraaltredes en kruisen ook zichzelf, zoals in de inzet is te zien. De oorzaak van deze wonderlijke tredekruisingen is de verplaatsing van dislocaties na het groeien. Door krachten van buitenaf zijn sommige schroefdislocaties verplaatst, waarbij ze een onregelmatig tredespoor achter zich laten. Deze sporen, die bestaande tredepatronen kunnen doorkruisen, leiden uiteindelijk naar een andere dislocatie met tegengesteld teken waarop annihilatie van de dislocaties volgt, of naar de rand van het kristal.

Foto aangeleverd door: Marco Plomp en Peter van Hoof, [Katholieke Universiteit Nijmegen](#)

Redactioneel: Teken van leven

Eindelijk is hij er: de eerste FACET van het nieuwe millennium! Het heeft even geduurd, maar we zullen voortaan met een hogere frequentie een nieuwe FACET laten uitkristalliseren. Uiteraard hebben we bij de daarvoor noodzakelijke kiemvorming wel uw input nodig. De drempel hiervoor is laag: aanleveren kan per brief, fax, [e-mail](#), of telefoon. En we staan natuurlijk open voor alle direct of indirect met de NVKG verwante onderwerpen; bijvoorbeeld:

- Aankondigingen van lezingen, symposia en congressen (niet alleen de activiteiten die u zelf organiseert, maar ook activiteiten waarover u langs andere weg geïnformeerd bent)
- Verslagen van (kristalgroei)-conferenties
- Artikelen (mag ook heel kort zijn!) over een opmerkelijke ontdekking
- Advertenties: bijvoorbeeld i.v.m. vacature
- Omslagfoto's (met toelichting). Telkens zal de beste ingezonden foto op de omslag van de FACET worden afgedrukt samen met een korte toelichting aan de binnenzijde van het blad. Bovendien zullen de foto's op de fotogalerij van onze webstek worden gepost: (<http://www.kncv.nl/secties/kkn/index.html>)

[Joost Frenken](#)

Vernieuwing NVKG web site

Op de web site van de NVKG is informatie te vinden over de samenstelling van de vereniging, de activiteiten, jaarverslagen en er wordt een verzameling van interessante kristalgroei-links onderhouden. Verder wordt een fotogalerij bijgehouden rondom het thema kristalgroei. Op dit moment zijn we er mee bezig de site volledig "up to date" te brengen. Ook daarvoor hebben we dringend uw input nodig. Behalve de items die hierboven al zijn genoemd, en die zowel in de FACET als op de web site zullen belanden, hebben we dringend behoefte aan de volgende input:

- Hyperlinks naar uw bedrijf, of instelling
- Hyperlinks naar verwante sites in Nederland of in het buitenland
- "Dooie links" (dit zijn links die niet meer bestaan of die inmiddels zijn gewijzigd)

[Joost Frenken](#)

KRISTALGROEIMARKT

Vrijdag, 23 juni,
Aula Congrescentrum,
[Technische Universiteit Delft](#)
Mekelweg 5, Delft

Op vrijdag 23 juni organiseert [Herman Kramer](#), van het Laboratorium voor Apparatenbouw in Delft, de nieuwe KRISTALGROEIMARKT. Deze zal plaatsvinden in de Aula van de Technische Universiteit Delft.

Traditioneel vormt de KRISTALGROEIMARKT van de NVKG hét forum voor jonge onderzoekers in de kristalgroei om hun werk nationaal te presenteren. Elke KRISTALGROEIMARKT wordt georganiseerd rond een breed thema. Dit jaar is gekozen voor het thema *verontreinigingen*. De kristalgroeimarkt wordt gecombineerd met de algemene ledenvergadering 1999, die i.v.m. organisatieproblemen niet meer voor de jaarwisseling heeft kunnen plaatsvinden.

PROGRAMMA KRISTALGROEIMARKT; thema: *verontreinigingen*

09:30	Registratie en Koffie	
	Sessie 1:	
09:45	Ruthenium inbouw in InP	Frank Heinrichsdorff
10:05	De groei van Pd nanokristallen op TiO ₂	M. Jak
10:25	Diffusie in een kristaloppervlak: de atomaire schuifpuzzel	Joost Frenken
10:45	Koffie + postersessie	
	Sessie 2:	
11:45	Molecular modelling and crystallisation: crystal shape	Joop ter Horst
12:05	Eutectic freeze crystallisation	Raymond Vaessen
12:25	Crystallisation kinetics in a DTB crystalliser	Gerrit Westhoff
12:45	Lunch + posters	
14:00	Algemene ledenvergadering 1999	
	Sessie 3:	
14:15		
14:35	<i>wordt nog ingevuld</i>	
14:55		
15:15	Rondleiding op Laboratorium voor Apparatenbouw voor de Procesindustrie, Leeghwaterstraat 44	
16:30	Borrel op API	

Agenda algemene ledenvergadering NVKG 1999

Vrijdag, 23 juni 2000, 14.00 uur, Aula Technische Universiteit Delft.

1. Opening
2. Verslag van de algemene ledenvergadering 1998 (20 november 1998, Petten)
3. Jaarverslag van de NVKG 1999
4. Financiën
5. Mededelingen van het bestuur
6. Activiteiten 2000
7. Bestuursmutaties
8. Rondvraag
9. Sluiting

How to come to the Aula congress Centre and the Laboratory for Process Equipment

Delft University Quarter Den Haag

API = Laboratory for Process Equipment
Leeghwaterstraat 44

A13

Aula congress centre
Meekelweg 5

Exit Delft-Zuid

Rotterdam

By bus from Delft central station;
To Aula: Lines 60,63 121 129 201
To API: Lines 63, 121,129, 201

Aanmeldingsformulier kristalgroeimarkt

Opsturen bij voorkeur per e-mail aan: [H.J.M. Kramer](mailto:H.J.M.Kramer)

- Hierbij meld ik me aan voor de Kristalgroeimarkt 2000
- Ik wil graag van de mogelijk gebruik maken om een poster te presenteren.
De titel van mijn poster luidt

Van de deelnemers wordt een bijdrage in de kosten gevraagd van f 30.—

Gaarne dit bedrag bij registratie te betalen of het bedrag over te maken op giro rek, 422372 t.n.v. Stichting Beg ond. Ind. krist., Leeghwaterstraat 44 2628 CA Delft

Correspondentie: H.J.M. Kramer, Delft University of Technology, Laboratory for Process Equipment
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Notulen van de jaarvergadering van de NVKG ECN, Petten, 20 november 1998

Aanwezig zijn 18 leden waaronder 6 bestuursleden

Opening van de vergadering

De voorzitter opent de vergadering om 13:00. Hij heet de aanwezigen welkom.

Verslag van de vorige ledenvergadering

De notulen worden goedgekeurd.

Jaarverslag NVKG 1997/1998

De volgende activiteiten zijn ontplooid
Excursie naar de ECN in Petten is helaas door de geringe deelname komen te vervallen
Paon Cursus Industriële kristallisatie en Precipitatie
Anglo Dutch meeting is dit jaar georganiseerd door de Engelse zusterorganisatie en is gehouden op 22-23 september 1997 in York

Financiën

De penningmeester deelt financiële verslag uit aan de aanwezigen en geeft een korte toelichting
In het vervolg worden de contributie over twee jaren gecombineerd.

De f 20000,-- die als lening (renteloos) is verstrekt aan de organisatie van de ICCG 12 in Den Haag is nu weer teruggestort en weer in de boeken opgenomen.
Er is lange tijd onduidelijkheid geweest omtrent dit bedrag omdat in een accountant verslag de bijdrage van de NVKG ten onrechte werd aangemerkt als een schenking. Daardoor leek het of de zomerschool winst had gemaakt en kon de NOVEM dit bedrag terugvorderen. Uiteindelijk is echter alles uitgepraat en het volledige bedrag aan de NVKG teruggestort. Er zijn nog 2 boeken verkocht van de zomerschool à f 200.—De rest zal tegen een gereduceerde prijs (f 50,--) worden aangeboden.

De kascommissie bestaande uit de heren van Kessel en Boon heeft de jaarstukken gecontroleerd en in orde bevonden
De penningmeester wordt gedetacheerd en bedankt voor zijn inspanning.

Mededelingen van het bestuur

Er zijn het afgelopen jaar weinig activiteiten geweest. De voorzitter doet een appel op de leden om zich wat actiever op te stellen.

Nieuwe activiteiten

De Facet zal in de toekomst per e-mail worden verzonden. Bij de laatste proef om de facet per e-mail te verzenden traden weinig problemen op. We blijven de facet ook per post versturen voor de leden die dat wensen.
Daarnaast zal de webpagina worden gebruikt als communicatie medium. André van Geelen zal de organisatie daarvan op zich nemen. Het plan is om een soort galerie te maken van de activiteiten van de vereniging en van haar leden. Ook samenvattingen van proefschriften kunnen op de webpagina van de vereniging worden gezet.

Kristalgroeprij

Oproep voor aanmeldingen voor de kristalgroeprij: indienen voor augustus 1999.

Samenwerking met NVK

Er is door het bestuur overleg gevoerd met de voorzitter van de NVK, Tuinstra over mogelijke samenwerking met deze vereniging. Het bestuur acht een fusie met deze vereniging niet aan de orde wel wordt de mogelijkheid overwogen om gezamenlijke activiteiten te organiseren.

Statutenwijziging i.v.m. naamswijziging
In verband met de naamswijziging van KKN in NVKG moeten de statuten worden gewijzigd. Het concept hiervoor is inmiddels gereed en wordt binnenkort gerealiseerd.

Bestuursmutaties

Geen

Komende activiteiten

Bridge meeting on Crystal Growth: 14-17 maart 1999, Zeist. Dit wordt een meeting met Engelse en Duitse zusterverenigingen. De selectie van de sprekers is rond. De circulaire is gereed en wordt rondgestuurd.

Kristalgroeimarkt: een datum is nog niet beschikbaar.

De voorzitter sluit de vergadering

[Herman kramer](#)

Jaarverslag van de Nederlandse Vereniging voor Kristalgroei (NVKG) november 1998-november 1999

Secretariaat NVKG

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Ledenbestand NVKG

Per 1 oktober 1999 bedroeg het aantal leden van de vereniging 137.

Bestuur NVKG

Prof. dr. J.W.M. Frenken	voorzitter
Dr. ir. H.J.M. Kramer	secretaris
Dr. R. Geertman	penningmeester
Dr. H.H.C. de Moor	lid
Dr. A. van Geelen	FACET
Prof. dr. J. van der Eerden	lid
Prof. dr. E. Vlieg	lid

Nieuwsbrief / Tijdschrift

Het verenigingsblad FACET zal zoveel mogelijk elektronisch worden verspreid. Voor leden, die niet gebruik wensen te maken van e-mail blijft er een mogelijkheid om de Facet per post te blijven ontvangen.

Activiteiten 1999

Excursie naar ECN in Petten

Op 20 november 1998 is een excursie georganiseerd naar ECN in Petten waar een mini-symposium werd gehouden over de opwerking van elektriciteit en de rol van materialen daarin. Hierbij werd aandacht besteed aan twee conversie systemen:

- Zonnecellen
- Brandstofcellen

Met name werd de rol van halfgeleiders en keramiek in deze conversiesystemen gepresenteerd

Het symposium werd afgerond met een excursie langs een aantal testopstellingen.

Bridge meeting on Crystal Growth

14-17 maart 1999, Zeist

Meeting met Engelse en Duitse zusterverenigingen. Session topics:

- fundamental research
- high resolution surface imaging
- mass crystallisation
- biological systems, proteins, bio-mineralisation
- single crystals and films for electronics.

7e Nederlandse Symposium voor Scanning Probe Microscopy,

1 november 1999, Technische Universiteit Eindhoven.

Naast een buitenlandse voordracht over actuele ontwikkelingen op het gebied van Scanning Probe Microscopy werd een breed scala aan toepassingen van Scanning Probe Technieken in Nederland gepresenteerd door jonge Nederlandse wetenschappers.

Overige activiteiten op het gebied van kristallisatie in 2000:

Spring 2000 Materials Research Society Meeting San Francisco, April 24th - 28th including a symposium Morphology and dynamics

Paon cursus Industriële kristallisatie en precipitatie, 14- 17 maart 2000 in Delft

Webpagina NVKG

Er is een begin gemaakt met de [webpagina](#) voor de vereniging. Het bestuur heeft het voornemen om hier ook een ledenlijst in op te nemen met enkele persoonlijke gegevens en desgewenst een link naar de webpagina van hun bedrijf of instelling. Ook wordt gestreefd naar een galerij op het gebied van kristalgroei-onderzoek in Nederland.

[Herman Kramer](#)

Recente proefschriften

Peter van Hoof

Titel proefschrift	<i>Growth and Morphology of n-Paraffine Crystals</i>
Gepromoveerd	25 mei 1998, Katholieke Universiteit Nijmegen
Promotor	Prof.Dr. P.Bennema
Copromotor	Dr. W.J.P. van Enkevort

The crystallisation of n-paraffins in crude oil and its products is well known, but undesired in the petroleum industry. Crude oil and petrochemical products consist of a significant amount of n-paraffins which, upon cooling crystallise, starting with the longer chain homologous. This results in the blockage of filters and tubes, amongst others in diesel powered engines, and the formation of slack-wax during the production of lubricates. The present study aims to investigate the growth habit and different growth characteristics of n-paraffins when crystallising from apolar (paraffinic hydrocarbons) and more polar (containing media). This is done by experiments, e.g. growing and characterisation of crystals, Monte Carlo simulations and theoretically.

First, a morphology study has been performed. In chapter 2 a complete connected net analysis of orthorhombic n-paraffins, which are the subject of interest in this thesis, have been performed. It shows that 71 different connected nets, corresponding with 16 crystal faces can be identified. Some multiple connected nets result in symmetry roughening and some probably result in pseudo-symmetry roughening. This will cause their absence on the growth form or decrease their morphological importance. Finally the growth form of $n-C_{23}H_{48}$ constructed which will be bounded by the {001}, {110}, {111} and {010} faces. Especially the occurrence of the {111} faces is striking and this has not found by other studies.

To be able to compare these results with experiments, C_{23} crystals have been grown from different media, e.g. vapour, melt and solution. Chapter 3 discusses the results of these experiments. It shows that the growth

morphology of the crystals which have been grown from the vapour is very similar to the predicted morphology. All the predicted faces, including the {111} faces, have been observed. The crystals which were grown from solutions never showed faceted {010} faces and it was not possible to distinguish between the {110} and the {111} faces. The aspect ratio of these crystals is much larger crystals grown from the vapour, because they are much thinner.

Chapter 4 is based on calculations of Ising temperatures of (pseudo) hexagonal lattices. Many faces of organic compounds have a pseudo-hexagonal symmetry and the study presented in this chapter helps to understand the stability of these faces. It shows that if one out of three bonds is left out, the faces still have a very high Ising temperature. Furthermore it is shown that rather anisotropic faces still maintain relative high Ising temperatures. Finally, it is stated that the roughening temperature is much more dependent on the total energy of the bonds in the face than of the anisotropy in those bonds.

The first step in studying flow improvers is to study the effect of homologous impurities on the crystallisation of n-paraffins. Chapter 5 presents a study on the effect of three different homologous impurities on the morphology and growth of C_{23} and C_{25} crystals. Homologous impurities with a longer chain tend to reduce the thickness of the crystals to less than one micrometer. This induces new effects in the growth of the crystals. One was that the side faces were obstructed by dust particles, inducing "particle induced rough growth". Second, a Gibbs-Thompson effect was encountered.

Both phenomena have been observed in-situ and were measured quantitatively.

The observations of very thin crystals prompted us to start Monte Carlo simulations to study the effect of crystal thickness on the crystal growth parameters (chapter 6). Two important effects have been observed. First, the Gibbs-Thompson effect, which could be measured, both by simulation and by experiment. This effect is introduced by the surface tension and the finite size of the crystal systems. Second, a shift in roughening temperature of narrow crystal faces. For both phenomena analytical models have been developed.

Other Monte Carlo simulations have been applied to study the kinetic roughening of crystal faces (chapter 7). Simulations on inclined (001) Kossel faces have been performed to obtain growth rates, from which kinetic Wulff plots were constructed. To do so, analytical expressions were derived, which contain two important parameters: ϵ (a roughening parameter) and v_{step} (the velocity of the steps on the surface). Different criteria to characterise the on-set of kinetic roughening are compared with each other and with the roughening parameter ϵ . It shows that the transition from a flat to a rounded morphology of a crystal face is quite gradual. The different criteria used to identify kinetic roughening yield a broad range of transition points in the supersaturation-bond strength space.

Chapter 8 describes the thermal roughening of the side faces of $n-C_{25}H_{52}$ crystals grown from a apolar solvent (n-hexane) and a slightly polar solvent (toluene). The roughening transition of the side faces of crystals grown from n-hexane is a first order phase transition, whereas that of the crystals grown from toluene solutions is of infinite order. A possible explanation is that the n-hexane molecules, which are alike the $n-C_{25}H_{52}$ molecules, induce a solid phase transition at the surface of the side faces. This phase transition results in a sudden drop of the roughening temperature and in a first order roughening transition.

In chapter 9 this solvent effect has been investigated in more detail. The roughening and wetting of $n-C_{23}H_{48}$ crystals grown from mixtures of solvents have been studied. First, it is shown that mixtures of n-hexane and toluene behave as a regular solution. Second, the difference in wetting at the crystal-solution interface in different solvent mixtures, seems to be due to the different solute-solvent bond strength in the bulk of the solution and less due to a difference in bond strength at the interface. When the roughening temperature is compared to the bulk properties of the liquid it seems to be rather independent of the solvent composition. Thirdly, the addition of 25% of toluene to a n-hexane solution is enough to change the roughening transition from a first order to a higher, probably infinite, order phase transition.

Ex-situ AFM measurements on the {001} surfaces of $n-C_{23}H_{48}$ and $n-C_{40}H_{82}$ crystals have been presented in chapter 10. In this chapter it is shown that the AFM tip can induce growth and etching of the top faces of $n-C_{23}H_{48}$ crystals just as they were growing and etching in an in-situ environment. Several phenomena, such as spiral growth, two-dimensional nucleation and the pinning and bunching of steps, have been observed and discussed. In contrast, the {001} faces of the $n-C_{40}H_{82}$ crystals did not show any growth or etching when scanned by the AFM. The steps observed on these faces were very straight and sometimes crossed each other. It is suggested that the latter occurred after crystal growth, due to the movement of screw dislocations in the crystals.

The crystallisation of n-paraffins in crude oil and its products is well known, but undesired in the petroleum industry. Crude oil and petrochemical products consist of a significant amount of n-paraffins which, upon cooling crystallise, starting with the longer chain homologous. This results in the blockage of filters and tubes, amongst others in diesel powered engines, and the formation of slack-wax during the production of

lubricates. The present study aims to investigate the growth habit and different growth characteristics of n-paraffins when crystallising from apolar (paraffinic

hydrocarbons) and more polar media. This is done by experiments, e.g. growing and characterisation of crystals, Monte Carlo simulations and theoretically.

Reinier Grimbergen

Titel proefschrift *From Crystal Structure to Morphology*
Gepromoveerd 25 mei 1998, Katholieke Universiteit Nijmegen
Promotor Prof.Dr. P.Bennema
Copromotor Dr. H.L.M. Meekes

The work in this thesis can be divided into two parts:

Theory: chapter 2-5

Experiments and interpretation: chapter 5-10

In chapter 2 the Hartman-Perdok theory is reconsidered and an F-face is redefined as a crystal face having a roughening transition temperature larger than zero Kelvin ($T_{hkl}^R > 0$). It is demonstrated that a crystallographic orientation (hkl) which contains more than one connected net (i.e. surface configuration) may have a zero step free energy. When a pair of symmetry related connected nets gives rise to a zero step energy this is called *symmetry roughening*. The results of a connected net analysis are linked to the results of simple statistical thermodynamical surface models as described in literature. Finally, it is shown that the presence of multiple connected nets can have important implications for the prediction of the theoretical equilibrium and growth morphology.

In chapter 3 all symmetry relations between connected nets are categorized and their implications regarding symmetry roughening are discussed. It is shown that the cases of symmetry roughening are in a sense complementary to the classical BFDH law. Moreover, a distinction is made between microscopic and macroscopic symmetry roughening. Microscopic roughening is, like macroscopic roughening, caused by a symmetry related pair of connected nets, but does not give rise to a macroscopic roughening of the face.

The growth and equilibrium behaviour of crystal faces containing (symmetry) related multiple connected nets is studied in chapter 4. The results of a connected net analysis are compared with the results of Monte Carlo (MC) simulations. Apart from the well-known flat and rough surface phases also disordered flat (DOF) were identified for specific surface bonding structures. These surface phases may influence the growth behaviour of a crystal face dramatically. This is illustrated by calculation of the relative growth rates R_{hkl} of crystal faces (hkl) as a function of supersaturation by MC simulations. Specific crystal faces containing multiple connected nets can show anomalous growth behaviour due to (pseudo) symmetry roughening. Moreover, it is demonstrated that the classical recipes $R_{hkl} \propto 1/d_{hkl}$ and $R_{hkl} \propto E_{hkl}^{att}$ fail completely for these types of face. Using the relative growth rates of the MC simulations it is possible to predict the growth morphology as a function of supersaturation. In chapter 5 the phase diagram for the {011} faces of naphthalene is derived from a simplified restricted SOS model. The phase diagram consists of a flat, DOF and rough region. The DOF phase is separated from the flat phase by a preroughening transition line. MC simulations confirm the result of the statistical thermodynamical surface model and show a maximum in the specific heat $c(T)$ at T^{pr} . At the preroughening temperature the effective step energy decreases drastically which causes a significant lowering of the nucleation barrier. Therefore, the growth rate of a face in the DOF phase will be relatively high at low

supersaturation. However, MC simulations indicate that such a face still grows by a layer-by-layer growth mechanism.

Experimental evidence for the presence of a preroughening transition is presented in chapter 6. Vapour growth experiments of naphthalene and anthracene were done and anomalous growth behaviour was found for the {011} faces of naphthalene. These faces could be observed at very low supersaturations at 283 K. On increasing the supersaturation, the faces disappeared very rapidly already at very low supersaturation due to a sudden increase in growth rate. This behaviour is explained by the presence of a DOF phase.

Chapter 7 describes the results of a rigorous connected net analysis for orthorhombic n-paraffins. The complete set of connected nets is treated and all symmetry relations are analyzed. As a result it is found that the side face structure of n-paraffin crystals may, apart from the {110} faces, also show {100}, {010} and {111} faces.

The experimentally observed morphology of orthorhombic n-paraffin crystals grown from solution, melt and the vapour are compared with the theoretical prediction in chapter 8. For the first time flat {010}, {100} and {111} faces were observed on crystals grown from the vapour. The large aspect ratio of crystals grown from solution is explained in terms of the step free energy of those faces.

In chapter 9 the theoretical morphology of the industrially very important compound ϵ -caprolactam (a precursor for nylon-6) is derived. Due to the presence of hydrogen-bonded pairs of molecules in the crystal lattice the connected net analysis was done assuming both monomers and hydrogen-bonded dimers as growth units. The results of the two analyses are very similar. It is argued that, due to the presence of two stacked connected nets, the {110} faces may grow with half layers with a thickness d_{220} dependent on the growth conditions. Experimental data from literature show that the presence of these faces depends on the

solvent from which the ϵ -caprolactam crystals are grown.

The experimentally observed dependence of the supersaturation of the morphology of the protein lysozyme is explained in chapter 10. The crystals are bounded by {110} and {101} faces. At low supersaturations needles (along the c-axis) are observed, whereas at higher supersaturations block-like crystals are found which is in agreement with the attachment energy prediction. A detailed connected net analysis based on the crystal graph which contains only three bonds X, Y and Z predicts that pseudo symmetry roughening may occur for a certain bond ratio X:Y:Z. Based on the step energies of the three F-faces {110}, {101} and {111} it is possible to understand the dependence of the morphology on the supersaturation. The results are in agreement with previously published MC simulation data and the experimentally observed surface structure. There are strong indications that, depending on the temperature, DOF surface phases might occur for the face of lysozyme.

Chapter 11 treats the growth morphology of a series of cesium halides (CsF, CsCl, CsBr and CsI). Vapour growth experiments show a very distinct transition from a cubic ({001}, high temperature) to a dodecahedral ({110}, low temperature) morphology as a function of temperature and super-saturation. It is shown that the temperature is the critical parameter which determines whether the transition is observed. Moreover, the transition temperature depends on the halide. A connected net analysis yields the {001}, {110} and {111} faces as F-forms when only first nearest neighbour bonds are taken into account. In principle the connected nets found for {001} and {111} faces would cause symmetry roughening. However, when (repulsive) next nearest neighbour bonds are considered, it becomes clear that the {001} faces are stabilized by a c2x2 reconstruction. The relative growth rates of the {001} and {110} faces as a function of temperature were determined by MC simulations at a fixed supersaturation. The simulation results

confirm the experimentally observed transition from a cubic into a dodecahedral morphology when the temperature is increased. Moreover, our MC results are in agreement with the Ising transition temperatures as given by the phase diagram of the statistical thermodynamical staggered

BCSOS model. It is concluded that the observed dependence of the temperature is a result of a phase transition of the {001} faces from a reconstructed $c2 \times 2$ into a deconstructed rough or DOF phase dependent on the anisotropy.

Mischa Hoogeman

Titel proefschrift *Surfaces in Motion: A variable-temperature STM study*
Gepromoveerd 24 juni 1998, Universiteit Leiden
Promotor Prof.Dr. J.W.M. Frenken

This thesis describes experiments on the statistics and statistical mechanics of clean metal surfaces. The topics are the atomic-scale energetics of surfaces, surface phase transitions, and surface evolution. The experiments were performed with a scanning tunneling microscope especially designed for temperature dependent studies of surface phenomena. The microscope is designed such that appreciable temperature variations of the specimen hardly influence the position of the surface with respect to the tip. Over a temperature interval of 271 K one particular region can be kept within the microscope's limited field of view. The design and performance of this novel scanning tunneling microscope are described in chapter 2.

For a detailed understanding of most surface phenomena, knowledge of microscopic mechanisms and atomic-scale properties is required. Examples of atomic-scale properties are step and kink formation energies, interaction energies between steps and kinks, adatom/vacancy formation energies, and various diffusion barriers. The precise values of these energies determine the relative importance of possible phenomena and make it possible to predict the behaviour of the surface on the basis of simple theoretical models.

In chapter 3 and chapter 6 we measure the values of several atomic-scale energies. In chapter 6 we investigate the diffusion of kinks on Au(110). We unravel the two-step mechanism by which kinks move and

determine the values of the detachment barriers for an atom from the two possible kink configurations. Chapter 3 describes the measurements of the values of the kink formation energy and the step interaction energy on the vicinal Ag(115) surface. We make use of the high mobility of this surface to probe the probabilities of specific local geometries in the surface configurations. From the frequency distributions of the geometries we obtain accurate values of several atomic-scale energies.

The Terrace Ledge Kink (TLK) model of Villain, Gempel, and Lapujoulade [13] predicts the existence of a roughening transition of the Kosterlitz-Thouless type on vicinal surfaces. The temperature at which the surface loses its long-range flatness and becomes rough is determined within the TLK model only by the kink formation energy and the interaction energy between steps. In chapter 4 we investigate the roughening on Ag(115). The roughness is quantified by the mean-square height displacement. From a quantitative analysis of the mean-square height displacement we confirm the existence of a Kosterlitz-Thouless type roughening transition on this surface and determine the temperature at which this transition occurs. The temperature is compared with the prediction of the TLK model and the results of Monte Carlo simulations (chapter 5), where we used in both cases the measured kink formation and step interaction energy. The close agreement between the prediction

of the TLK model, the results of the simulations and the results of the experiment, justifies the simple terrace-ledge-kink description of the roughening transition of vicinal surfaces.

In Chapter 7 we describe the evolution of damaged surfaces. We show that the pathway along which the surface evolves towards equilibrium depends critically on the

amount of material in the topmost layer. One of these pathways, Ostwald ripening, is studied in more detail. We test the classical 'mean-field' ripening model against a 'local-field' model. The latter results in a better description of the data. Finally, we describe intriguing anomalies in the exchange rate and the coalescence of islands which are in close proximity of each other.

Steven de Vries

Titel proefschrift *Interface Structure of Growing Crystals*
Gepromoveerd 25 februari 1999, Katholieke Universiteit Nijmegen
Promotor Prof.Dr. E. Vlieg

The quality of crystals is to a large extent determined by the surface structure and dynamics during growth. The growth of many crystals is strongly influenced by the presence of impurities, defects, surface reconstructions or adsorption layers. This thesis describes X-ray scattering experiments in which the structure of crystal interfaces is determined in order to get an atomic-scale understanding of the kinetic and thermodynamic processes involved in growth. The first part of this thesis is concerned with crystals and their growth in an ultrahigh vacuum (UHV) environment, where the conditions of the surface can be controlled very well. In the last two chapters we describe experiments on a crystal in its growth solution.

In homoepitaxial growth of Ag(111) it is known that by adding a surfactant like Sb the growth mode can be changed from three dimensional (rough) to layer-by-layer (smooth). The equilibrium surface structure of an Sb-covered Ag(111) surface depends on the Sb coverage. For coverages below 1/3 monolayer, the Sb atoms substitute for Ag atoms at normal fcc positions in the top surface layer. There is no lateral ordering of the Sb atoms. At a coverage of 1/3 monolayer a $(\sqrt{3} \times \sqrt{3})R30^\circ$ reconstruction is formed. We have determined the atomic structure of this reconstruction for the Ag(111)-Sb as well as for the similar

Cu(111)-Sb surfaces (chapter 2). Contrary to previous reports we found that all top layer atoms reside at stacking fault positions. Each $(\sqrt{3} \times \sqrt{3})R30^\circ$ surface unit cell contains one substitutional Sb atom. We determined the out-of-plane relaxations of the top layer atoms and the in-plane distortions in the second layer. When Ag is deposited on this surface at 100 ° C, the Sb segregates and the Ag atoms return to the correct fcc stacking, while the new Ag atoms in the top layer again have the hcp stacking. This thus effectively leads to a floating stacking fault. Because of kinetic limitations, the same effect occurs for Sb coverages below 1/3 monolayer. For growth above 100 ° C, all lower lying Ag layers return to the correct stacking, and no twin crystallites are formed. In chapter 4 we study a model solid-liquid interface. We present a structural analysis of the β -Ge(111) $(\sqrt{3} \times \sqrt{3})R30^\circ$ -Pb \rightarrow 1 x 1 phase transition at ~180°C for a Pb coverage of 1.25 monolayer. Below the phase transition the β phase has a saturation coverage of 4/3 monolayer. Our atomic structure model for this phase, consisting of three Pb atoms on off-centered T_1 sites and one on a H_3 site in the unit cell, is consistent with other studies reported for this system. We find that above the phase transition the single layer of Pb gives rise to a ring of diffuse scattering indicative of a two-dimensional liquid. However, of all the Pb

geometries considered, an ordered layer with large in-plane thermal vibration amplitude is found to provide the best agreement between calculated and measured structure factors. The Pb atoms appear to rapidly diffuse over the surface, but spend a significant fraction at the lattice sites that are occupied at the low temperature β -phase. The Pb layer has thus both liquid and solid properties.

Although most crystals are grown from the liquid phase, the atomic structure of the growing interface is hardly studied because of a lack of suitable techniques. Most surface science techniques need a UHV environment and cannot be applied to surfaces in a fluid. X-ray diffraction using the latest synchrotron radiation facilities makes these studies feasible for the first time. We have studied the interface atomic structure of the inorganic crystal KDP. KDP crystals are grown from an aqueous solution. *Ex situ* measurements were performed in vacuum and in air. In order to be able to do *in situ* measurements, where the crystal is in contact with its growth solution, we have designed and built a crystal growth chamber which is compatible with X-ray diffraction experiments (chapter 6). The surface atomic structure has been determined of the two natural existing faces, the prismatic {100} and pyramidal {101} faces. We found that the {101} faces are

terminated by a layer of K^+ ions and not by $H_2PO_4^-$ groups, resolving a long-standing issue that could not be predicted by theory (chapter 5). From our measurements we cannot find clear differences between the surface structure in air, vacuum or in solution. However, the quality of the surface, also as function of time, is better controlled *in situ*.

It is known that when trivalent metal ion impurities like Fe^{3+} or Cr^{3+} are present in the growth solution the macroscopic crystal habit is elongated in the direction of the pyramidal faces. From the atomic structure of the two different faces in solution, we can explain this phenomenon. With only K^+ ions on the {101} face of the crystal, impurity ions will experience a large barrier for adsorption onto the positively charged face. The {100} face has both the positive K^+ ions and the negative $H_2PO_4^-$ at the interface. On these faces cations can adsorb easily, and small amounts of these ions will already block the growth. When Fe impurities are added to the saturated KDP solution, no evidence was found for an ordered Fe layer on the prismatic face. However, the surface becomes significantly more rough. The impurities locally pin the moving steps, which causes an increased meandering of the steps leading to a rougher surface.

Gertjan Bögels

Titel proefschrift
Gepromoveerd
Promotores

Growth Mechanism of (111)-Twinned fcc Crystals (ISBN 90 373 0466 4)
20 april 1999, Katholieke Universiteit Nijmegen
Prof.dr. P. Bennema en dr. H.L.M. Meekes

Silver halide face centered cubic (fcc) crystals can, besides in the common cubic habit under certain conditions also be grown with a tabular morphology. Tabular or platy silver halide crystals are produced in the photographic industry in large amounts. These tabular crystals, which are multiply twinned are used because photographic films containing tabular crystals need a lower amount of silver as compared to block-shape crystals. This is because around the surface

of silver halide crystals the photographic process takes place and tabular crystals have a relatively large surface. Still the quality of the photographic emulsions used can be improved by producing batches which are more homogeneous and by decreasing the number of other (twinned) crystals in the crystal batch. For this a better understanding of the growth mechanism and twin formation for silver halide crystals is needed. This thesis addresses both topics. Models to

explain the growth mechanism and twin formation of twinned silver halide crystals are presented together with experiments to validate these. The developed models are not only relevant for silver halide crystals but can also be applied to other NaCl-type structures and fcc metals.

The side-face structure and the preferential growth mechanism of tabular silver bromide crystals grown from DMSO are studied in chapter 2. Tabular silver bromide crystals grown from DMSO are over a thousand times larger than micrometer-sized crystals grown by the industrial double-jet precipitation method in water. The larger size makes the determination of the fast growing side faces possible. The crystal sides consist of {100} and {111} faces separated by parallel {111} twin planes. The number of twin planes is deduced from the morphology and the proposed twinned cubo-octahedron model. The preferential lateral growth is explained by a substep model. The substep model is based on the twin-lamella theory of Ming Naiben which explains the increase of growth rate of fcc crystals with parallel (111)-type twin planes and stacking faults. Fast growing {100} faces present on the crystal sides are capable of increasing the growth rate of the slower growing {111} side faces owing to the twin plane. {100} faces are linked via a twin plane to a {111} side face. At the twin plane position the growing {100} side faces can produce substeps on the {111} side faces. Substeps will easily form steps on the {111} side face, a complete growth layer will be formed and the growth rate of the whole crystal side will be increased.

In the third chapter tabular silver bromide crystals are grown at various circumstances. Increasing the growth rate of the {100} faces (as compared to the {111} faces) leads to tabular crystals with higher aspect ratios containing side-face structures with smaller {100} side faces. For these tabular crystals the {100} side faces are present between the twin planes and adjacent to the tabular {111} faces. The {100} side faces adjacent to the tabular faces will grow out because of their

higher growth rate. {100} faces between the twin planes can not grow out and will still increase the growth rate of the other {111} side faces owing to the substep mechanism. Thus, the relation between the relative growth rate of the {100} faces (as compared to the {111} faces) and the side-face structure and aspect ratio is revealed. At conditions where the {100} faces grow fast only one side-face geometry expresses preferential lateral growth. Tabular crystals bounded by other side-face geometries grow more slowly and will dissolve in the physical ripening process. Thus, homogeneously shaped crystals are formed after the physical ripening stage.

The step source on the crystal sides was made visible by optical microscopy as presented in the fourth chapter. Tabular crystals with relatively low aspect ratios (relatively large crystal sides) are examined on which growth patterns on the {100} and {111} side faces are clearly visible. The in-situ observation reveal that the (100) side faces (present between the twin planes) is the step source for both adjacent {111} side faces. The position of the parallel twin planes can be made visible by etch techniques.

In chapter 5 silver bromide and silver chloride crystals grown from the vapour phase are studied. Cubic, cubo-octahedral, needle-shaped and {111} and {100} tabular crystals are observed. The morphology of the crystals is dependent on the driving force. At low driving forces {100} faces are stable whereas at higher driving forces the {111} faces become stable. Twinning occurs above a threshold driving force. This threshold driving force is comparable for silver chloride and silver bromide. The observed vapour grown morphologies are the same as obtained for pure silver bromide grown from precipitation and with the extractive crystallization in DMSO. For the vapour grown crystals the driving force is constant during growth, nevertheless, twin planes are only formed in the nucleation stage. At larger crystal sizes the chance of forming twin planes decreases. The twin formation is probably caused by

twinned two-dimensional nuclei which can grow out to form a twinned layer. This will only occur when the supersaturation is above a critical value and the crystal size is small enough. At larger crystal sizes the chance is high that also correctly stacked nuclei occur. These nuclei have a stronger binding energy and a higher growth rate. Therefore, the twinned stacked islands will have a high chance to dissolve again on larger crystals. This crystal size effect is studied in chapter 10.

In chapter 6, the position and the number of twin planes of micrometer-sized tabular silver halide crystals grown in water and in DMSO are studied using transmission electron microscopy (TEM). For the water grown tabular crystals also the side-face structures are examined. Tabular crystals contain two or three parallel $\{111\}$ -type twin planes which is in agreement with the number of twin planes deduced from the twinned cubo-octahedron model presented in chapter 2. The side-face structure of the water grown tabular crystals is analogous to that of the DMSO grown ones. Needle-shaped silver halide crystals grown from the vapour and from DMSO are examined in chapter 7. All needles studied contain non-parallel $\{111\}$ -type twin planes. The needles grown from DMSO have the same morphology as needles grown in water observed by Goessens et al.. For the vapour grown needles a rough face is present on the needle top between the non-parallel twin planes. This face is capable of increasing the growth rate of the whole needle top. The growth mechanism of both needles is explained by the substep mechanism.

In chapter 8, atomic force microscopy (AFM) studies on the $\{111\}$ and $\{100\}$ faces of tabular crystals are presented. In-situ growth experiments of the polar $\{111\}$ faces reveal monosteps with the height of the $\{111\}$

interplanar distance (d_{111}) and pinning of these steps. In-situ precipitation experiments show small nuclei on the tabular $\{111\}$ face. The observed nuclei contain twin planes with a separation between the twin planes of 40 nm, which is comparable to the results of the TEM measurements of chapter 6.

Silver metal crystals grown from the vapour phase are studied in chapter 9. Silver also crystallises in an fcc-structure. The morphologies observed are the same as those found for AgBr crystals. The twinning mechanisms of (tabular) Ag and (tabular) AgBr and AgCl crystals are analogous. This gives new insight in the twinning mechanism and the role the charge plays.

In chapter 10, Monte Carlo simulations of the twinning event are presented. These simulations serve as a test for the hypothesis concerning the twin formation in chapter 5. The chance of forming twin planes is studied as a function of the supersaturation, the crystal size and the ratio of the vertical bond strength of a twinned unit and the vertical bond strength of a correctly stacked unit. Increasing the crystal size leads to a decrease in the chance of forming twinned layers. This is in agreement with the results obtained for vapour grown silver and silver halide crystals. Increasing the supersaturation leads to an increase in the chance of forming twin planes. Above a certain threshold supersaturation dependent on the stability of twinned growth units, less completely twinned layers are formed. This is owing to the splitting of the surface above a certain driving force. For multiply twinned silver and silver chloride crystals grown from the vapour phase the ratio between the numbers of parallel and non-parallel twinned crystals is in reasonable agreement with the results deduced from the presented model.

Marco Plomp

Titel proefschrift *Crystal growth studied on a micrometer scale*
Gepromoveerd 13 december 1999, Katholieke Universiteit Nijmegen
Promotores Prof.dr. E. Vlieg en Prof.dr. P. Bennema
Co-promotor Dr. W.J.P. van Enkevort

This thesis is a collection of eleven crystal growth studies, which have their subject and the observation technique used in common. All of them deal with crystal faces, which are studied mostly with the help of atomic force microscopy (AFM).

The basic question that the science of crystal growth tries to answer is: *How does a large amount of separate building blocks (atoms, ions, molecules) evolve into a macroscopic crystal with a number of specific crystal faces?* The research presented in this thesis is addressed to one aspect of this general question: *How does one particular crystal face grow?*

In many cases, crystal faces are not roughened en growth proceeds layer by layer, in which every new layer of growth units spreads over the surface via steps. *In situ* and *ex situ* AFM provides a relatively easy way to image these monomolecular step patterns. The high resolution of AFM even enables direct imaging of the molecular surface lattice.

Within the general resemblances mentioned above, there is a large diversity of the subjects in this thesis. Most eye-striking is the difference in investigated crystals: ionic crystals on one hand, and organic crystals (paraffins, fats and proteins) on the other hand. In addition, the topic of the various crystal surface studies also varies: crystal growth, crystal dissolution, cleavage, the influence of the AFM itself on the crystals.

The first two chapters treat the growth mechanisms of barium nitrate crystal faces. The presence of several types of screw dislocations, leading to different types of growth spirals on the {111} and {100} crystal faces, as well as the occurrence of 2D nucleation on these faces, is elaborated in chapter 1. Chapter 2 deals with the occurrence and the size of the hollow cores

that can emerge at the spiral centres. The size depends on both the dislocation's burgers vector magnitude and the supersaturation during growth. This behaviour is predicted by theoretical calculations, which seem to hold remarkably well for the small burgers vectors involved.

The third chapter addresses the growth of silver bromide tabular crystals, which are important for the photographic industry. Several *ex situ* and *in situ* AFM observations indicate that these crystals grow with layers of one AgBr growth unit. Furthermore, observations of nucleated crystals confirm the occurrence of twinning, which is the key mechanism for the growth of tabular crystals. The next four chapters are all about potassium bichromate (KBC). This crystal has many interesting properties, such as the opposite (001) and (00 $\bar{1}$) crystal faces that grow completely different, despite the $\bar{1}$ crystal symmetry as determined by X-ray diffraction. Further, the crystal structure is composed of alternating ionic layers A and B parallel to {001}. In the first KBC chapter the growth of the deviating (00 $\bar{1}$) face is studied. It appears that the steps of one or a few unit cells in height are relatively easily blocked, while macrosteps of hundreds or even tens of thousands unit cells in height can still grow, and will develop to micro-facets. This phenomenon often leads to the formation of 'caves' in the crystals, which is attributed to the combination of impurity blocking and volume diffusion effects. In the second KBC chapter the double layered structure perpendicular to <001> is treated in more detail. In case of cleavage of a crystal along {001}, the cleavage plane is between layers A and B or between B and A, depending on the cleavage direction, as a result of the crystal symmetry. From these experiments, together with the KBC dissolution

experiments described in chapter 7, it is proven that the A layer is thermodynamically the most stable layer, and is almost always on top of both opposite {001} crystal faces. When freshly cleaved crystals are exposed to air, the upper B layer that is present on one crystal half dissolves and recrystallizes as A. This process is facilitated by the ultrathin water layer that forms on most crystals exposed to air. This water layer is also detected by the use of tapping mode AFM (TM-AFM) on KBC crystals exposed to air, as is demonstrated in chapter 8. The water layer introduces a large attractive capillary force between the TM-AFM tip and the crystal, and this again induces mode switching between an attractive and a partly attractive, partly repulsive mode. This results in an AFM image having holes of a few nm depth, which correspond to these mode switches rather than to real topographic height differences.

The first part of the thesis deals with ionic crystals, while in the second part some crystals of organic substances are studied. These molecules form much larger growth units than ions. The Van der Waals bonds keeping the crystals together are relatively small, which makes the crystals softer than in the ionic case.

The first 'organic' chapter deals with the spontaneous movement of screw dislocations in paraffin crystals after cessation of growth. If this happens, a screw dislocation leaves a capricious step as a trace, that can intersect the straight spiral steps formed during growth and even itself. The movements are induced by shear strains, which probably are caused

by adhesion between thin crystal sheets. In chapter 10 paraffin crystals with a melting point that is relatively low, but still well above room temperature, are studied by means of TM-AFM. It appears that the AFM tip, which is heated by a focused laser beam in order to measure its deflection, locally melts the crystal surface. A liquid bridge between tip and sample evolves, and transport of liquid paraffin molecules towards or from the tip takes place, which corresponds to etching or growth of the crystal surface, respectively. In this way, melt growth of paraffin can be studied '*in situ*' by AFM.

In chapter 11, the relation between crystal structure and surface morphology is examined in a detailed way. As an example, the morphology of growth spirals on fat crystals is compared with the surface morphology as deduced from the crystal structure by different methods. It follows that the combination of Hartman Perdok theory and step kinetics is the best method to predict two-dimensional morphology.

The final chapter consists of an *in situ* AFM investigation of the growth of insulin protein crystals. Three types of growth were discerned: 2D nucleation, spiral growth and a form of 3D nucleation. If screw dislocations are present in the crystal, spiral growth dominates at the low supersaturations applied. If these are absent, the crystals are forced to grow by 2D nucleation. Occasionally, large aggregates or crystallites land on the mother crystal and grow out laterally. Only a weak overlap of the diffusion fields of the steps was recorded.

Voor aankondiging algemene ledenvergadering NVKG 2000

De algemene ledenvergadering 2000 van onze vereniging zal worden georganiseerd door André van Geelen bij het bedrijf Uniphase Netherlands B.V. te Eindhoven, op vrijdag 3 november 2000. De vergadering wordt gecombineerd met een lezingenprogramma en een rondleiding. Als thema voor deze dag is vastgesteld:

III-V Semiconductor: from niche applications to mainstream market

Het volledige programma wordt zo spoedig mogelijk bekend gemaakt.

Oproep voor aanmelding voor de NVKG kristalgroei prijs 2000

In 2000 zal wederom de NVKG-prijs voor kristalgroei, bestaande uit een oorkonde en een geldbedrag, worden toegekend aan een jonge onderzoeker voor hoogstaand wetenschappelijk onderzoek op het gebied van de kristalgroei.

De prijs is bedoeld voor de auteur van het beste proefschrift of daarmee gelijkwaardige serie van publicaties (bijvoorbeeld opgesteld in een industriële context). Het proefschrift dient in de periode van maximaal vier jaar voorafgaand aan het jaar van toekenning van de prijs te zijn verdedigd aan een Nederlandse universiteit. De wetenschappelijke publicaties dienen eveneens te zijn verschenen in deze periode. Voor de toekenning van de prijs komen jonge Nederlanders in aanmerking en niet-Nederlanders die hun onderzoek in Nederland hebben verricht. De eisen voor de toekenning zijn dat de kandidaat moet hebben getoond te beschikken over grote bekwaamheden als onderzoeker alsmede over wetenschappelijke originaliteit en productiviteit. Bovendien moet de kandidaat een goed inzicht bezitten in de problemen op het vakgebied van de kristalgroei.

De toekenning van de prijs geschiedt door het bestuur van de NVKG op basis van een aanbeveling door de selectiecommissie, die bestaat uit drie deskundigen. De voorzitter van deze commissie is Prof. dr. J.W.M. Frenken. Indien er aan het bestuur geen kandidaat wordt voorgedragen, zal geen prijs worden toegekend. Vanwege het geringe aantal aanmeldingen in 1999 heeft het bestuur besloten om de prijs in 1999 niet toe

te kennen en de kandidaten die in 1999 werden aangemeld mee te laten dingen naar de kristalgroei prijs 2000.

Het bestuur van de NVKG geeft iedereen de gelegenheid om de aandacht te vestigen op kandidaten voor de NVKG-prijs voor kristalgroei. Degenen die hiervan gebruik wensen te maken worden verzocht de naam van de kandidaat, een korte schriftelijke uiteenzetting van de argumenten waarom betrokkene in aanmerking komt, een kort curriculum vitae en een verzameling publicaties en/of een exemplaar van het proefschrift in drievoud te sturen aan de voorzitter van de selectiecommissie. De kandidaatstelling dient vertrouwelijk te geschieden.

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