ACCGE-18 ABSTRACT

On Transients in Detached Bridgman Growth

K. Mazuruk[a], M. P. Volz[b]

[a]University of Alabama in Huntsville, Huntsville, AL 35762, USA
[b]NASA, Marshall Space Flight Center, EM31, Huntsville, AL 35812, USA

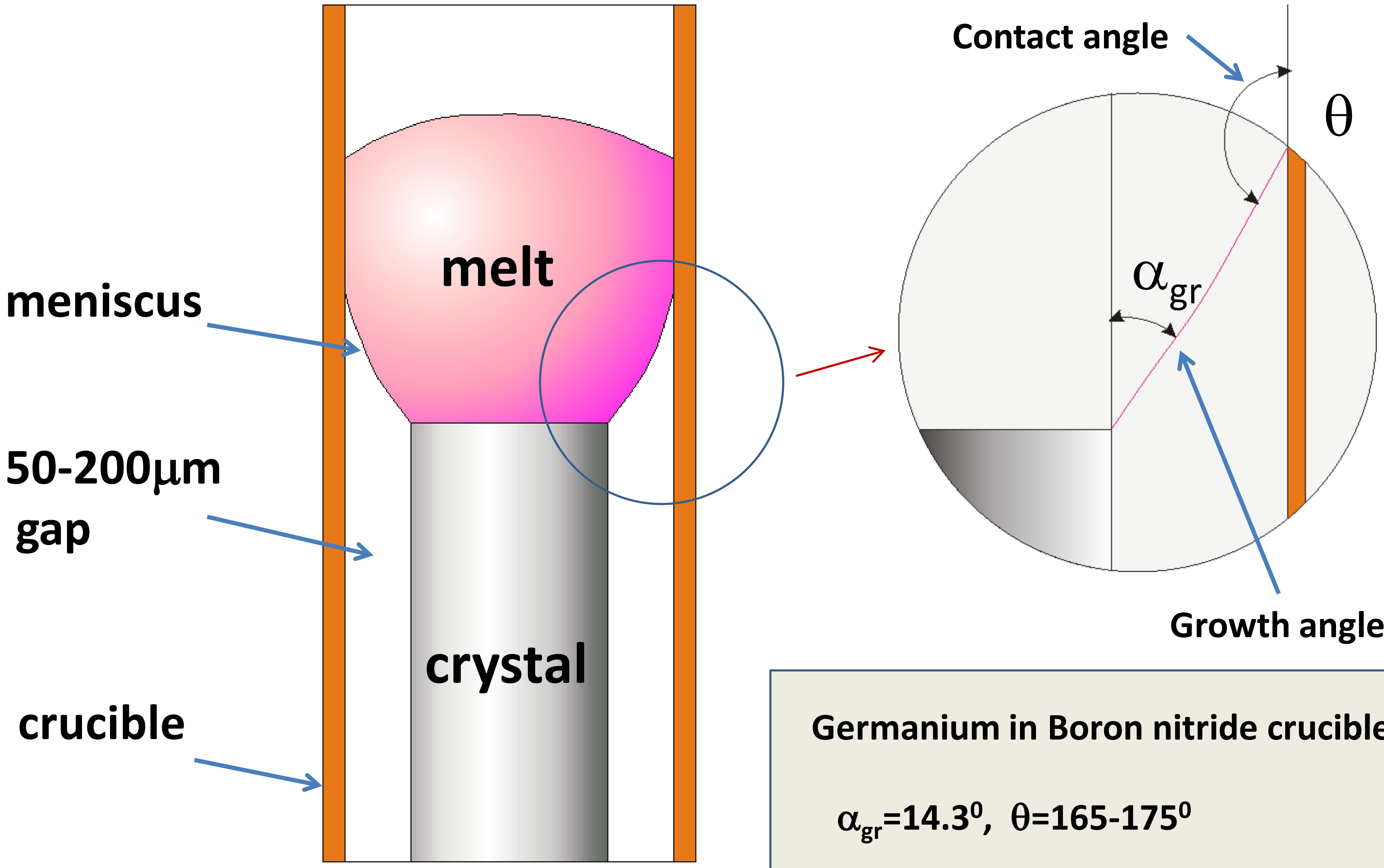
Abstract

In detached Bridgman growth, a gap exists between the growing crystal and the crucible wall. According to crystal shape stability theory, only specific gap widths will be dynamically stable. Beginning with a crystal diameter that differs from stable conditions, the transient crystal growth process is analyzed. The transient shapes are calculated assuming that the growth angle is constant. Anisotropy and dynamic contact angle effects are considered. In microgravity, dynamic stability depends only on capillary effects and is decoupled from heat transfer. However, heat transfer will influence the crystal-melt interface shape. The local angles and the crystal-melt-vapor triple junction are analyzed and the applicability of the Herring formula is discussed. A potential microgravity experiment is proposed which would enhance our understanding of the detached growth dynamic stability problem.

On Transients in Detached Bridgman Growth

Konstantin Mazuruk, UAH
Martin P. Volz, MSFC/NASA

detached Bridgman growth

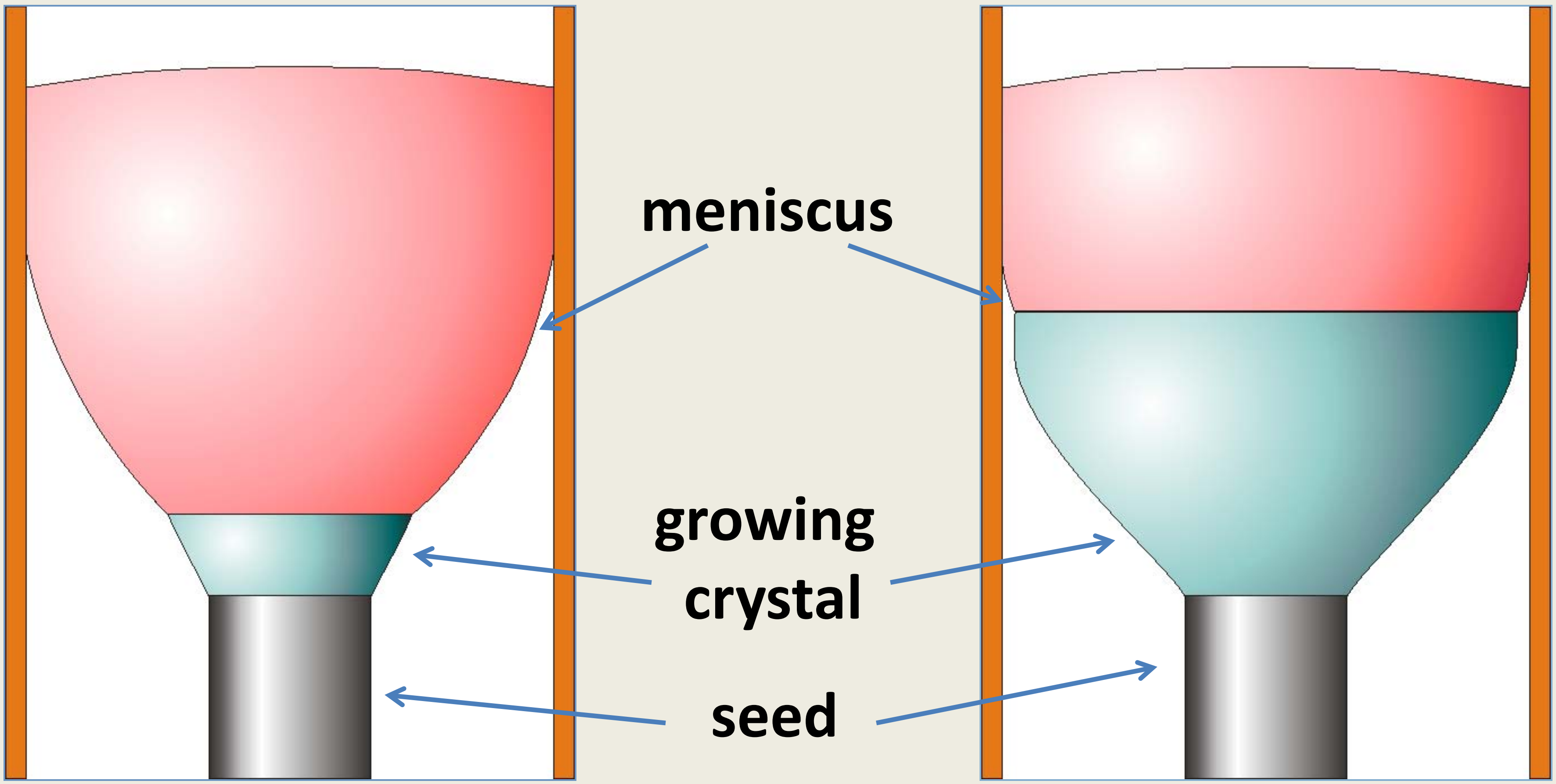


Germanium in Boron nitride crucible

α_{gr}=14.3^0, θ=165-175^0

microgravity experiment concept

Transient from the seed radius to the stationary detached growth radius



research motivation

• we propose to study a transient shape of the crystal growth from a small diameter to the diameter dictated by the stationary detached growth, in zero gravity.

• a novel technique to obtain simultaneously the growth and contact angles from the transient crystal growth shape is proposed. Advantage over the existing technique of drop solidification – no effects of growth process on the resulting shape. Shape is defined only by three parameters, two angles, and the pressure differential.

•Possible variations of the growth or contact angle can be estimated. Meniscus pinning effects, if present, will be possible to quantify.

•Effects of angular dependence on the crystal shape close to the singular crystalline directions can be experimentally investigated by careful analysis of the crystal shape.

stability of detached growth in microgravity

Scaling: distance by crucible radius, r_c

$$\Delta P = \left(P_{top} - P_{bot}\right) r_c / \gamma$$

Deflection of the growing crystal radius from the stationary condition
Is governed by the equation

$$\boxed{\delta \dot{R} = A_{RR} \delta R + \cancel{A_{Rh} \delta h}}$$

in microgravity, this second term is zero

Solution

$$\boxed{\delta R(t) = \exp\left(A_{RR} t\right)}$$

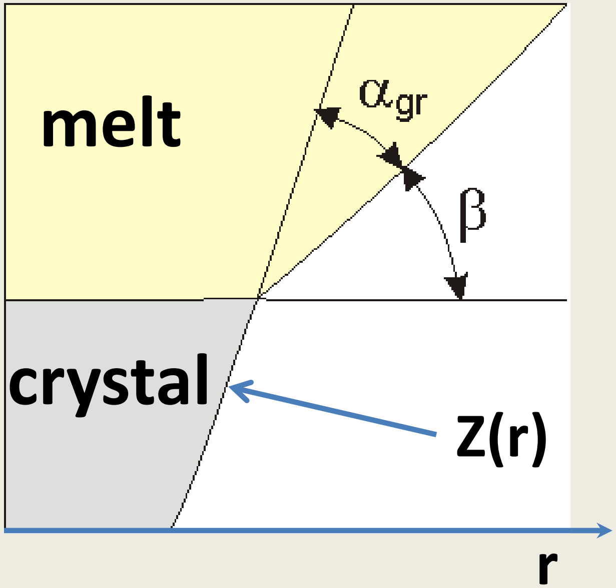
In terms of the crystal shape, *Z(r)* , we have a logarithmic singularity

$$\boxed{Z(r) = -\frac{R \sin \alpha_{gr}}{\Delta P \cdot R - \cos \alpha_{gr}} \ln\left|r - R\right|}$$

$$Z(t) = V_{gr} t$$

$$A_{RR} = -V_{gr} \frac{\left(\Delta P \cdot R - \cos \alpha_{gr}\right)}{R \sin\left(\alpha_{gr}\right)}$$

meniscus controlled crystal shape



Shape equation for zero gravity

$$\frac{dZ}{dr} = \tan(\alpha + \beta)$$

Meniscus equation for microgravity

$$\frac{\partial z}{\partial r} = \pm \frac{\Delta P\left(r^2 - 1\right) - 2\cos\theta}{\sqrt{4r^2 - \left(\Delta P\left(r^2 - 1\right) - 2\cos\theta\right)^2}}$$

Shape equation

$$\frac{dZ}{dr} = \frac{\sqrt{4r^2 - y^2}\tan\alpha + y}{\sqrt{4r^2 - y^2} - y\tan\alpha}, \qquad y = ar^2 - a - 2\cos\theta$$

zero gas phase pressure differential

Pressure differential from the top meniscus only

$$\Delta P = -2\cos\theta$$

crystal radius during stationary growth

$$R = -\frac{\cos\alpha_{gr}}{\cos\theta}$$

Meniscus shape

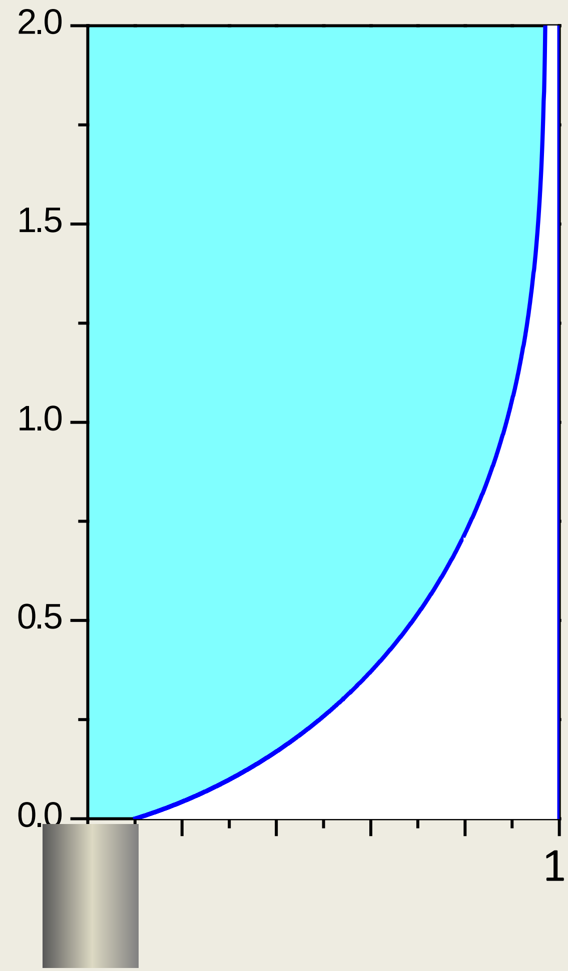
$$z = \frac{1}{\cos\theta}\left(\sqrt{1-r^2\cos^2\theta} - 1\right)$$

Crystal shape

$$Z(r) = \frac{\sin\alpha_{gr}}{2\cos\theta}\left[2\,\mathrm{arctanh}\left(\frac{\cos\theta}{\cos\alpha_{gr}}r\right) + \ln\frac{\sqrt{1-r^2\cos^2\theta} - \sin\alpha_{gr}}{\sqrt{1-r^2\cos^2\theta} + \sin\alpha_{gr}} + \frac{2}{\sin\alpha_{gr}}\sqrt{1-r^2\cos^2\theta}\right]$$

crystal shape for zero gas pressure drop

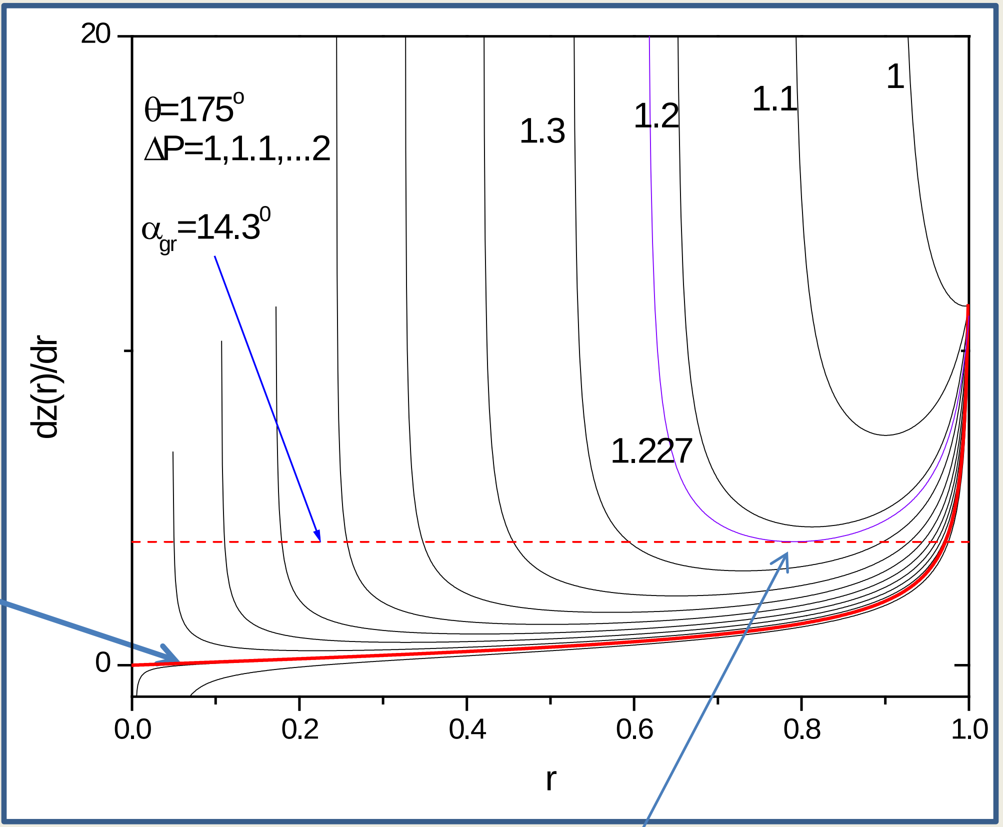
A shape of the crystal for the case of zero gas differential. The contact angle is 175^0, and the growth angle is 14.3^0.
The crystal seed radius is 0.1$r_{c.}$



meniscus in zero gravity

Meniscus shape derivatives for various pressure drops and for a given contact angle

For a range of pressure differential, two solutions exist for given contact and growth angles. The lower solution is, however, dynamically unstable.



Red solid line corresponds to the case of only upper meniscus contribution to the pressure drop.

$$R = \frac{1}{\sqrt{\Delta P}}\sqrt{\Delta P^2 + 2\Delta P\cos\theta + 2\cos^2\alpha_{gr} \pm 2\cos\sqrt{\Delta P^2 + 2\Delta P\cos\theta + \cos^2\alpha_{gr}}}$$

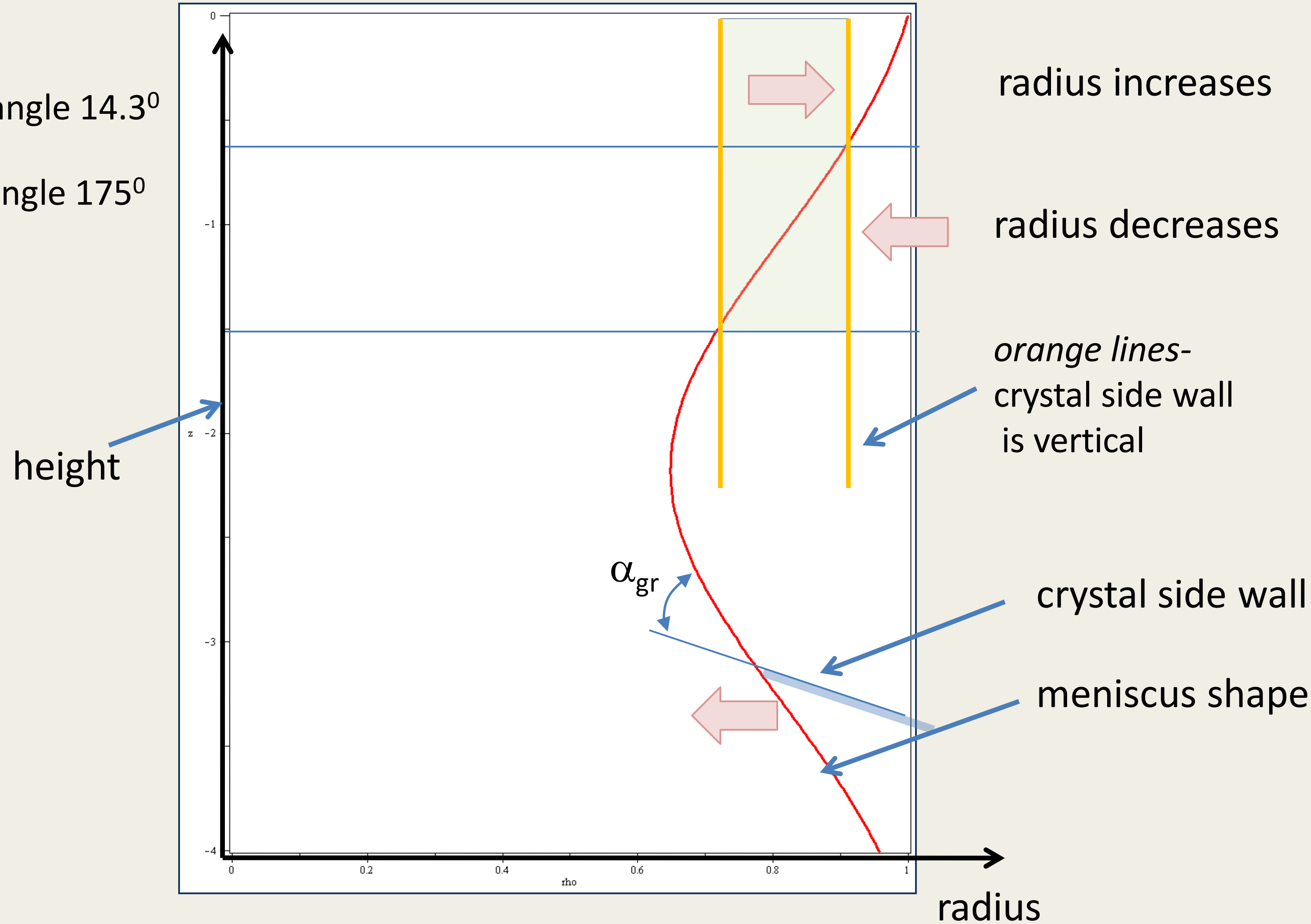
$$\Delta P_0 = \sqrt{\cos(\theta)^2 - \cos(\alpha_{gr})^2} - \cos(\theta)$$

transients in detached growth

Growth angle 14.3^0

Contact angle 175^0

$\Delta P=1.3$



summary

- A crystal shape theory of the transient from the initial condition to the stationary detached growth is proposed, valid for zero gravity.
- A novel technique is proposed to simultaneously measure both contact and growth angles from the transient shape.
- Second-order effects, such as meniscus pinning, or angular dependence of the growth angle, can be experimentally studied by analysis of the crystal shape.