

# **Novel FIB-based sample preparation technique for TEM analysis of ultra-thin gate oxide breakdown**

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# Outline

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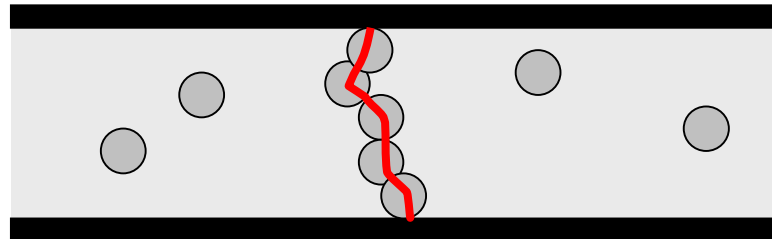
- ◆ **Properties of soft breakdown**
- ◆ **Microscopy and sample preparation challenges**
- ◆ **New approach**
- ◆ **First results**
- ◆ **Summary and Outlook**

# Theory of dielectric breakdown

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## Breakdown statistics

### trap percolation model

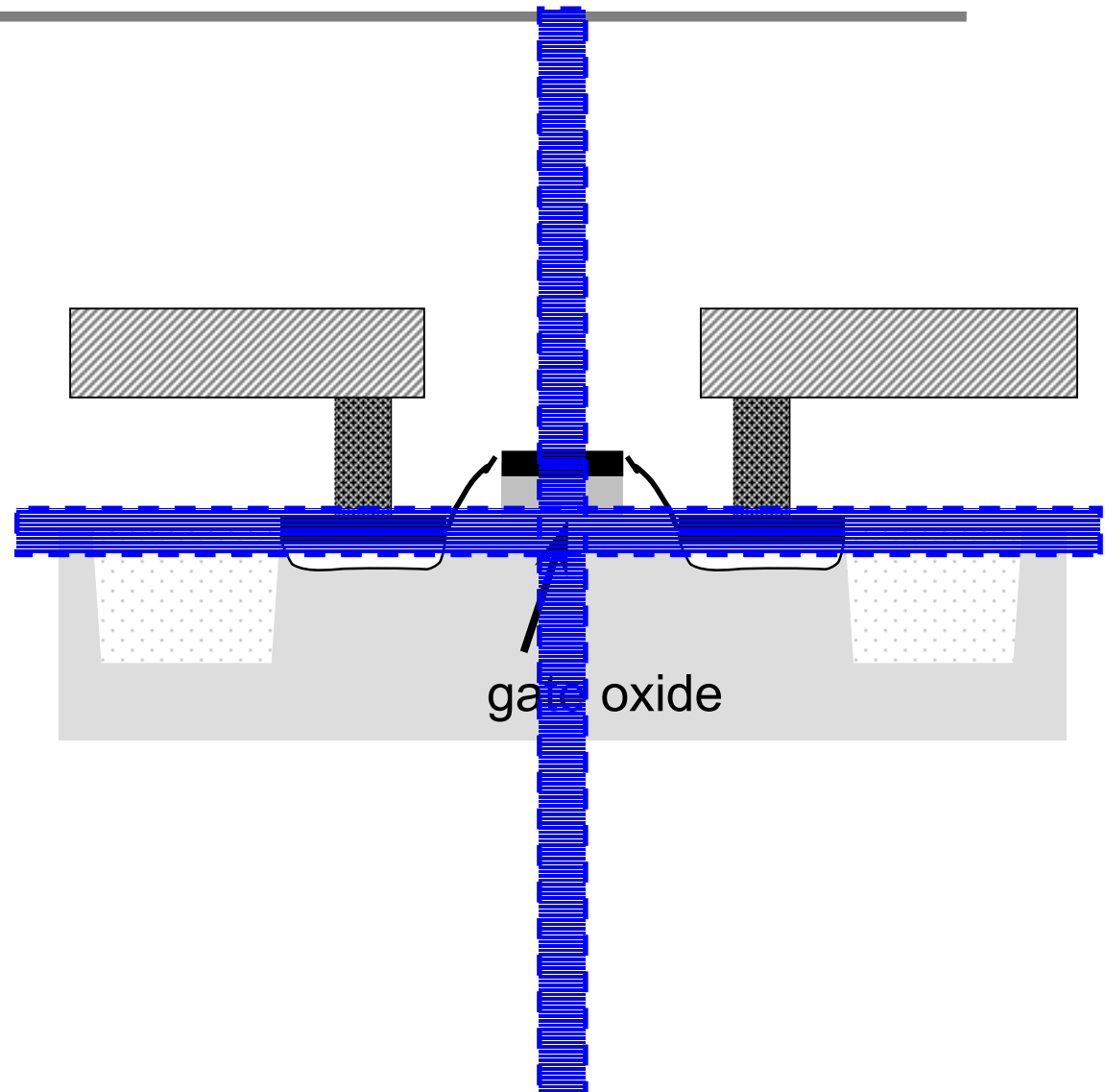


Ref.: Degraeve et.al. IEDM 1995

# Microscopy challenge

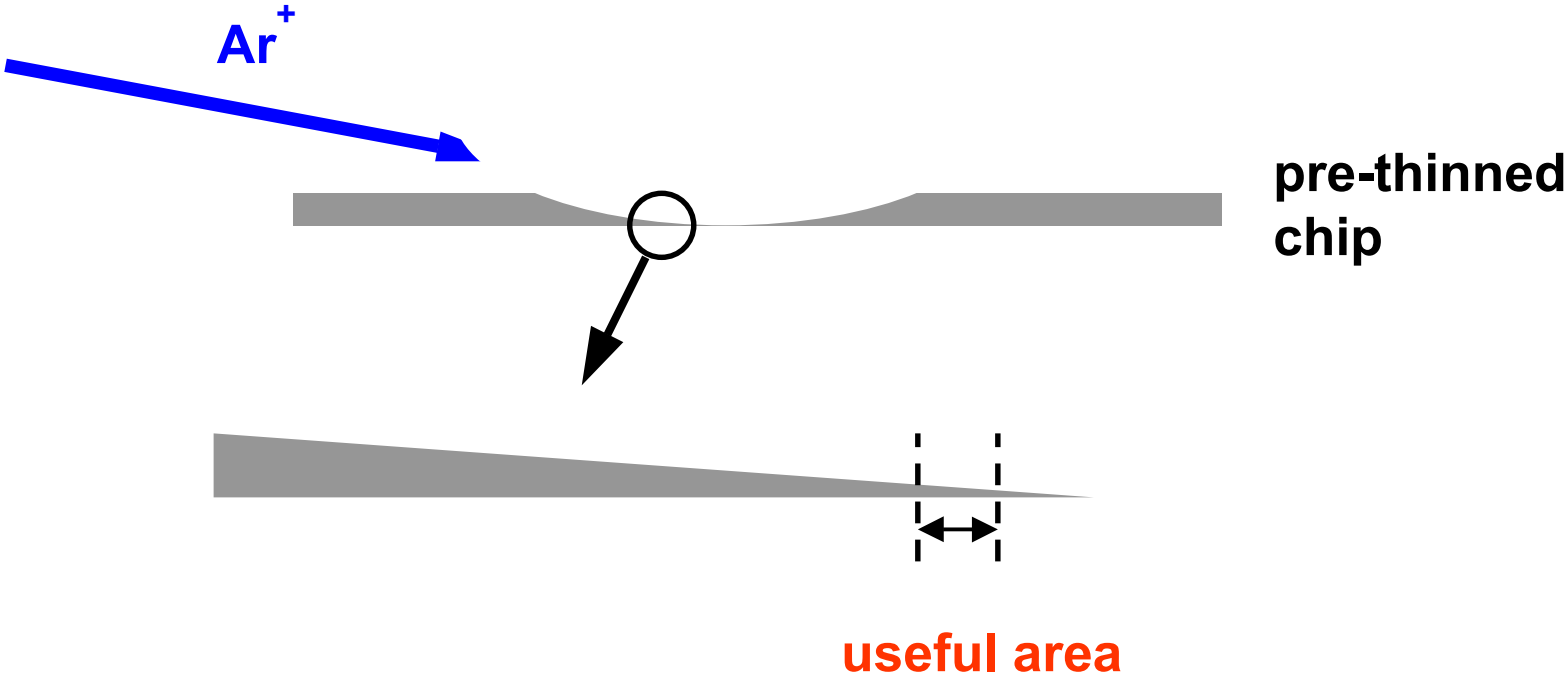
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- ◆ sBD site  $\approx$  1-10 nm
- ◆ visible structure change?
- ◆ TEM provides high-resolution non-destructive observation
- ◆ TEM lamella preparation
- ◆ lamella thickness 100 nm



# Horizontal lamella

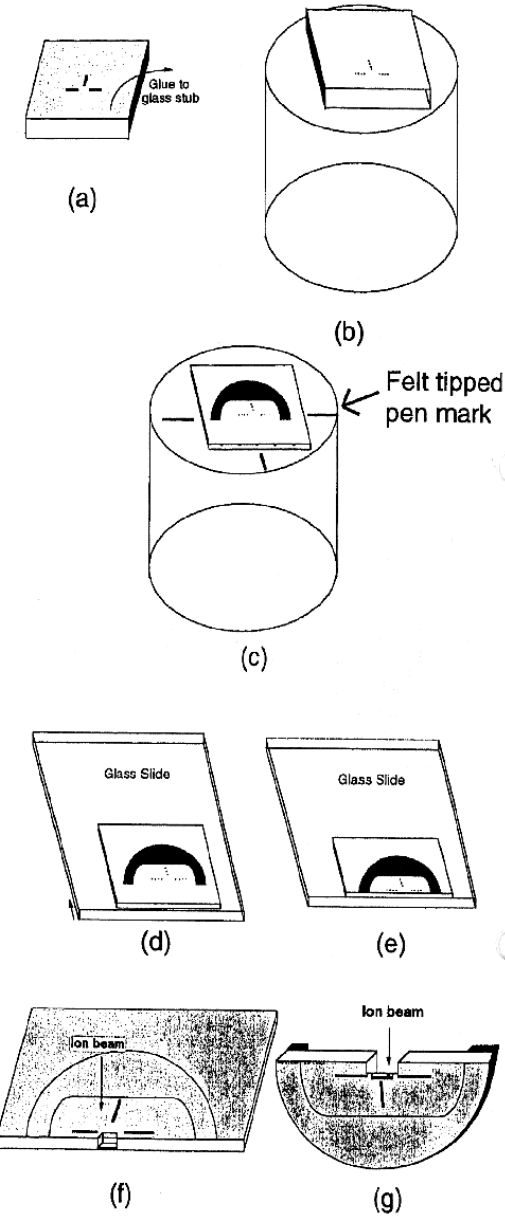
## Ar ion beam thinning



# Horizontal lamella - II

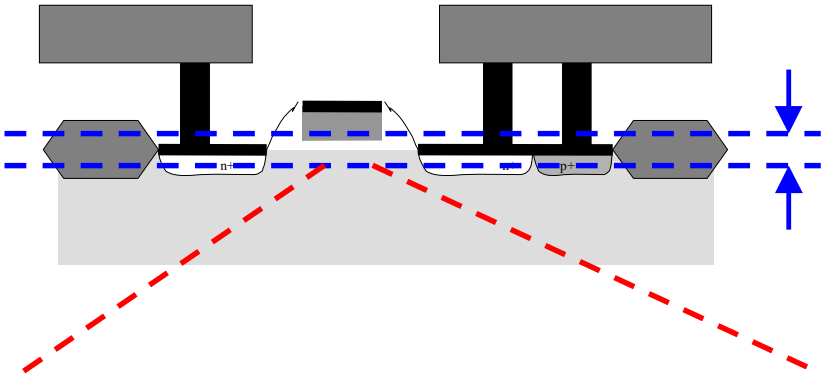
## SAPTEM

- ◆ thinning of chip to  $\approx 30 \mu\text{m}$
- ◆ polish (vertically to chip surface) to  $\approx 25 \mu\text{m}$  distance of the site
- ◆ bulk FIB cut
- ◆ planar FIB cut



Subramanian et.al., Motorola, ISTFA 1998

# Horizontal lamella - III



lamella

TEM beam

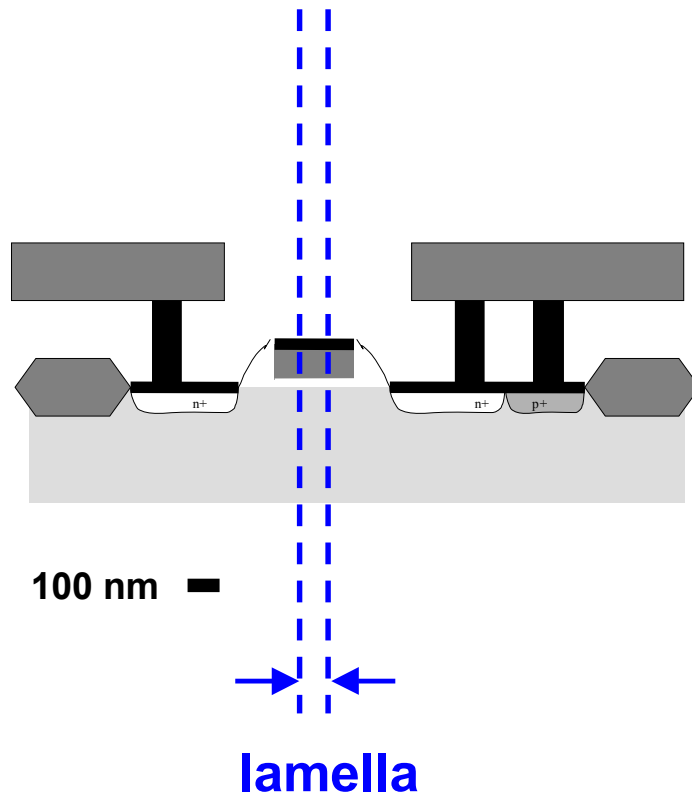


- poly-silicon
- gate oxide
- single crystalline silicon

◆ irregularities of the polysilicon gate material visible in TEM image

# Vertical TEM lamella using the FIB

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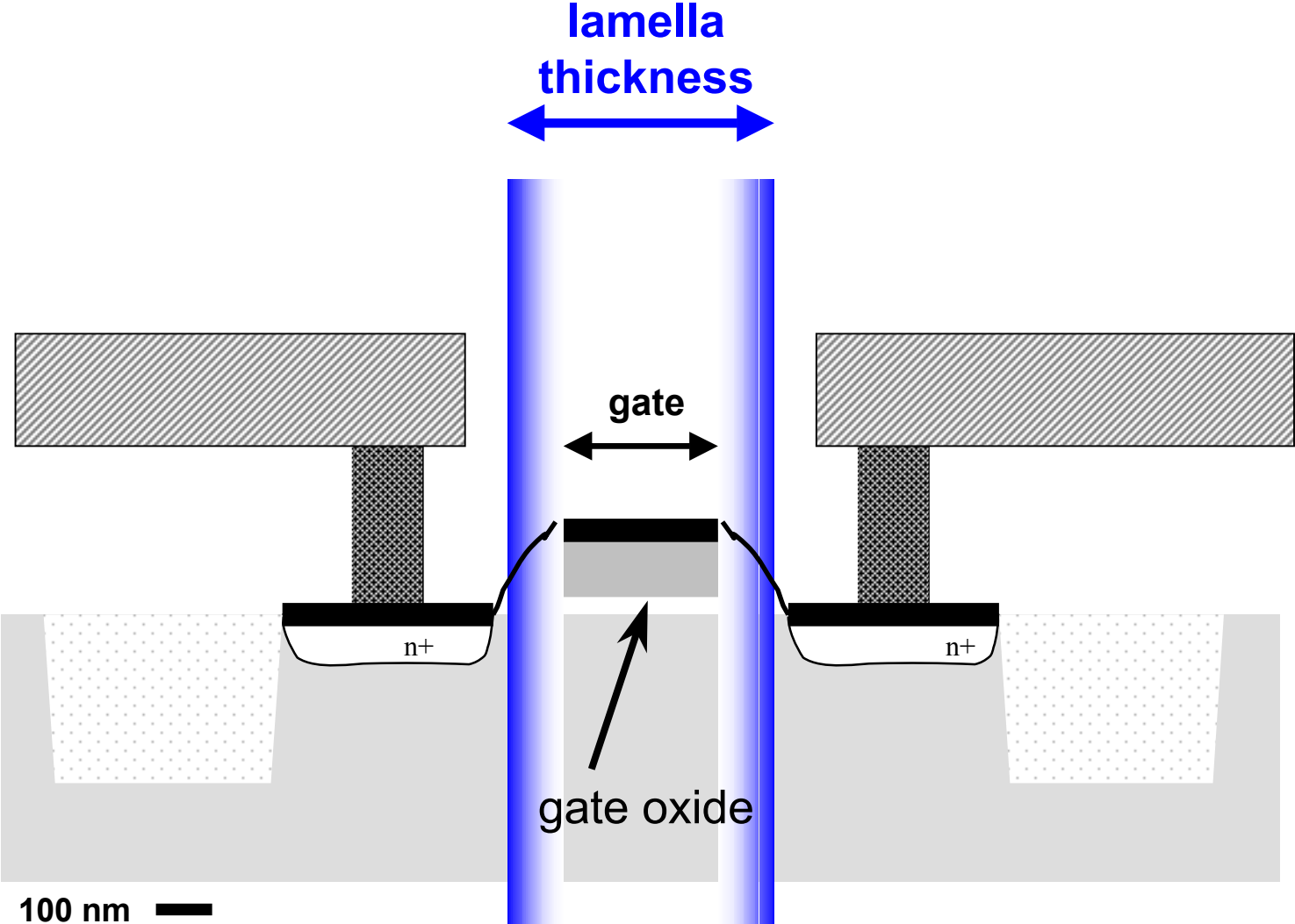
- ◆ TEM lamella thickness  $\approx 100$  nm
- ◆ defect localisation accuracy  $\pm 500$  nm
- ◆ 90 % probability to loose the damage site

# TEM lamella preparation methods

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	Ar-ion	vertical FIB lamella	SAPTEM	?
surface quality	excellent	moderate	moderate	at least moderate
other effects reducing sBD visibility	none	none	polysilicon grains	none
chance to hit point of interest	0 -1 %	10 %	90 %	90 %

# New approach

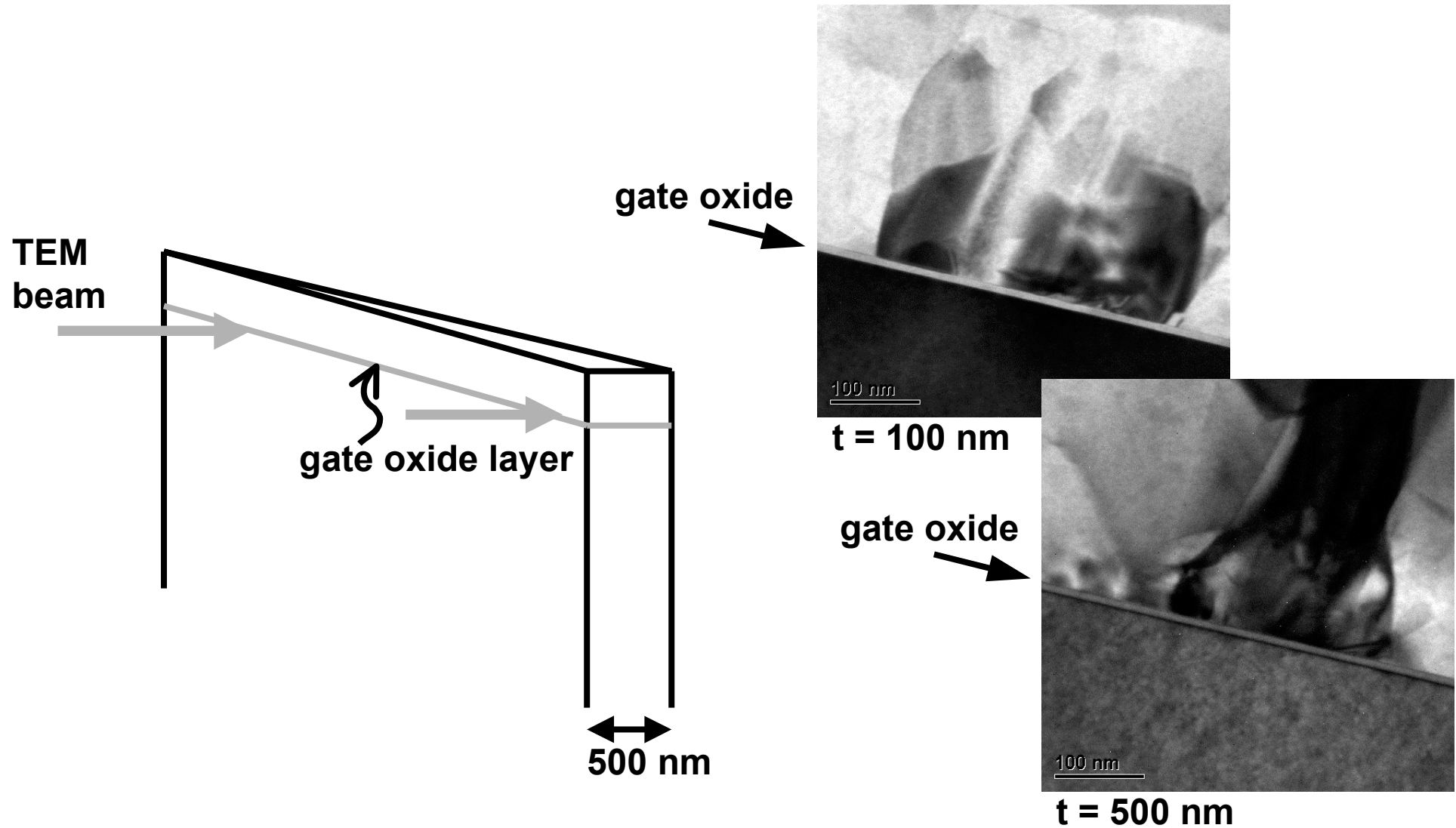


# Problems to be solved

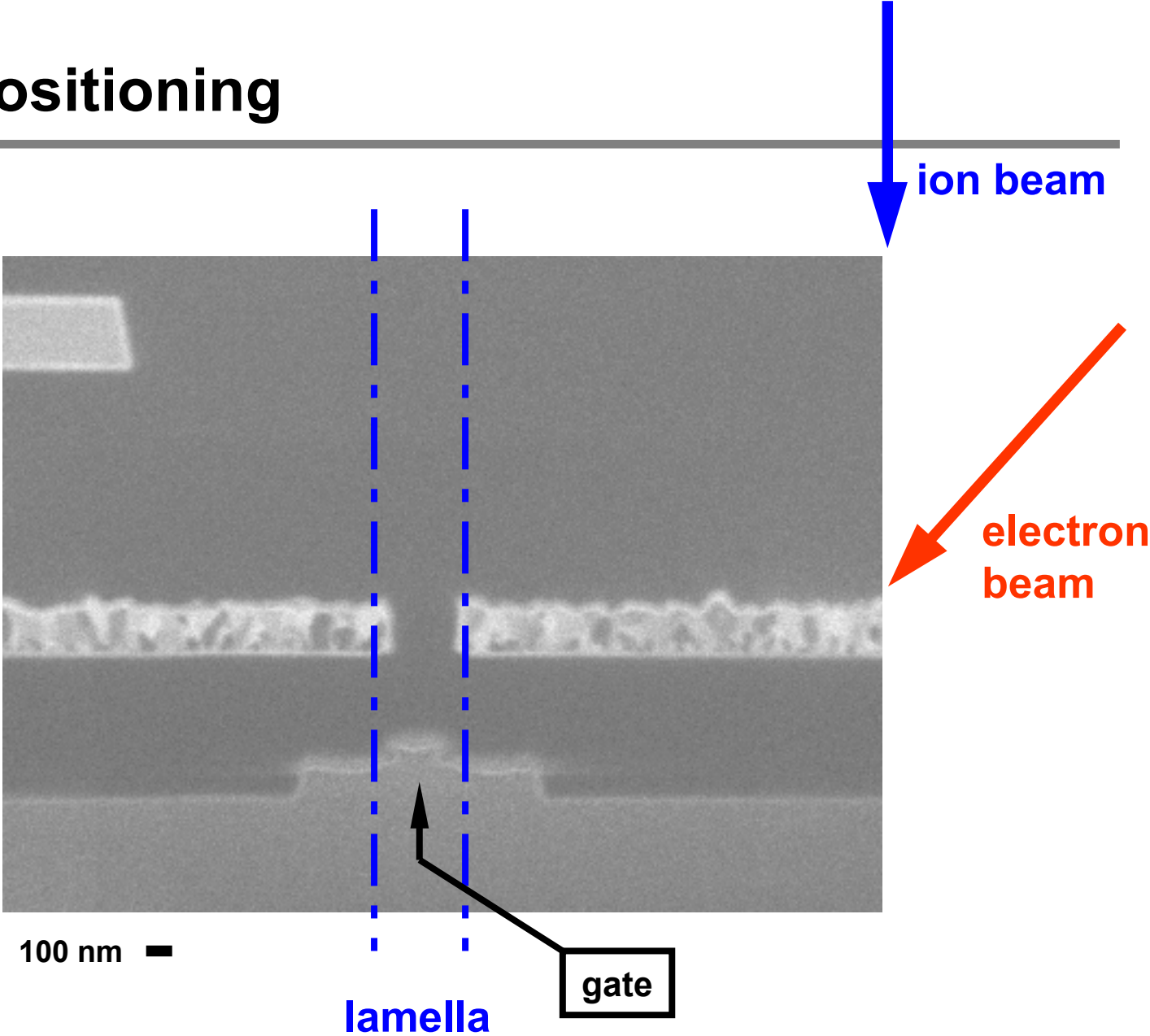
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- ◆ is TEM still possible for lamella thickness  $\gg 100$  nm ?
- ◆ can the FIB cuts be positioned accurately enough ?

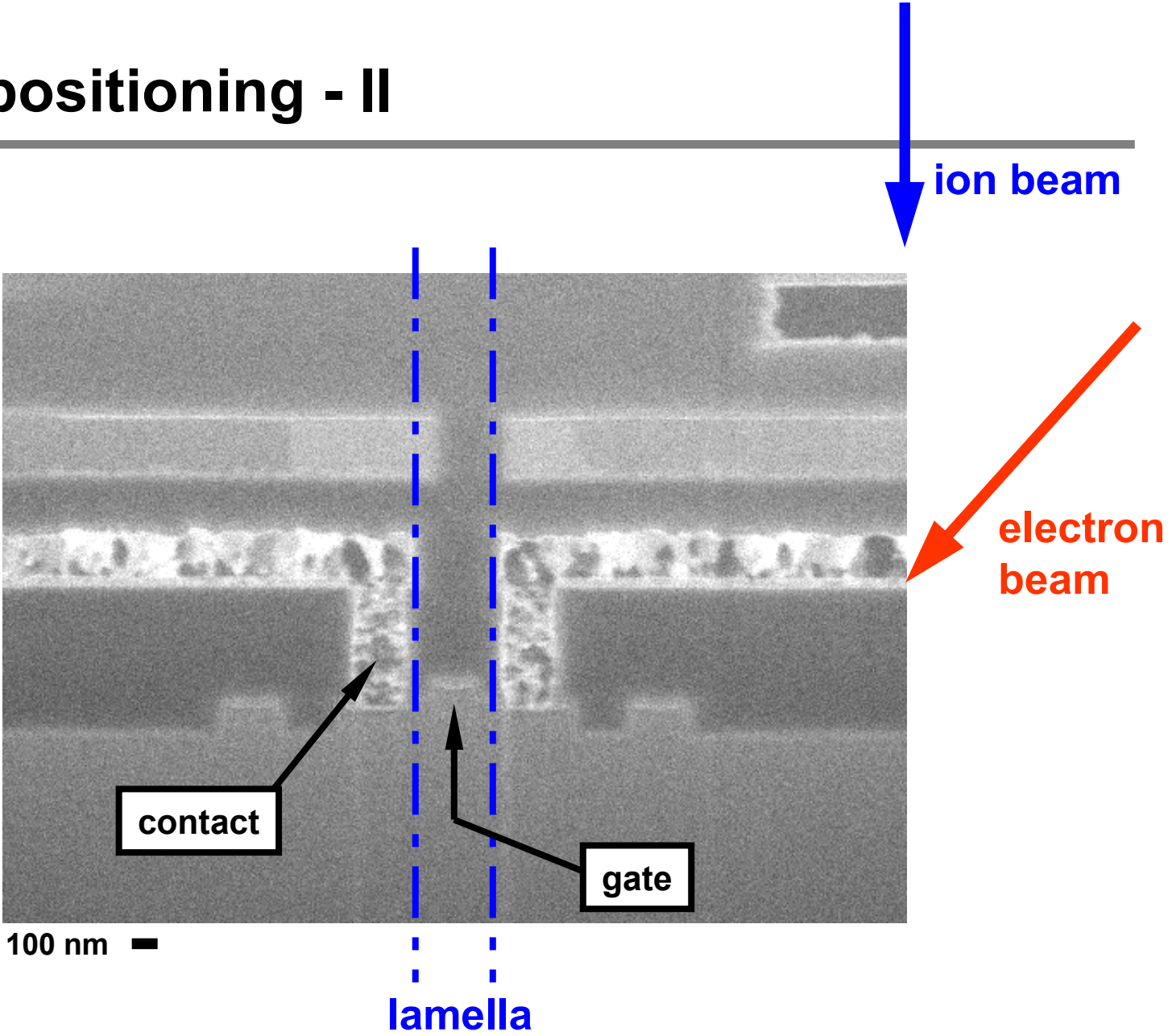
# TEM of thick lamella



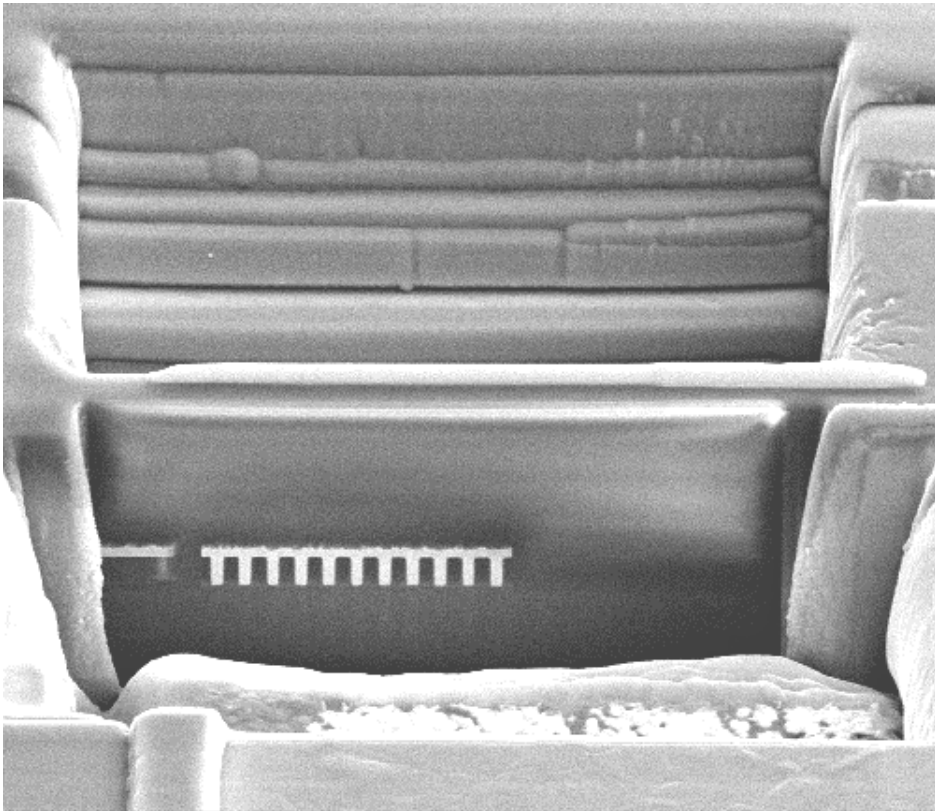
# FIB cut positioning



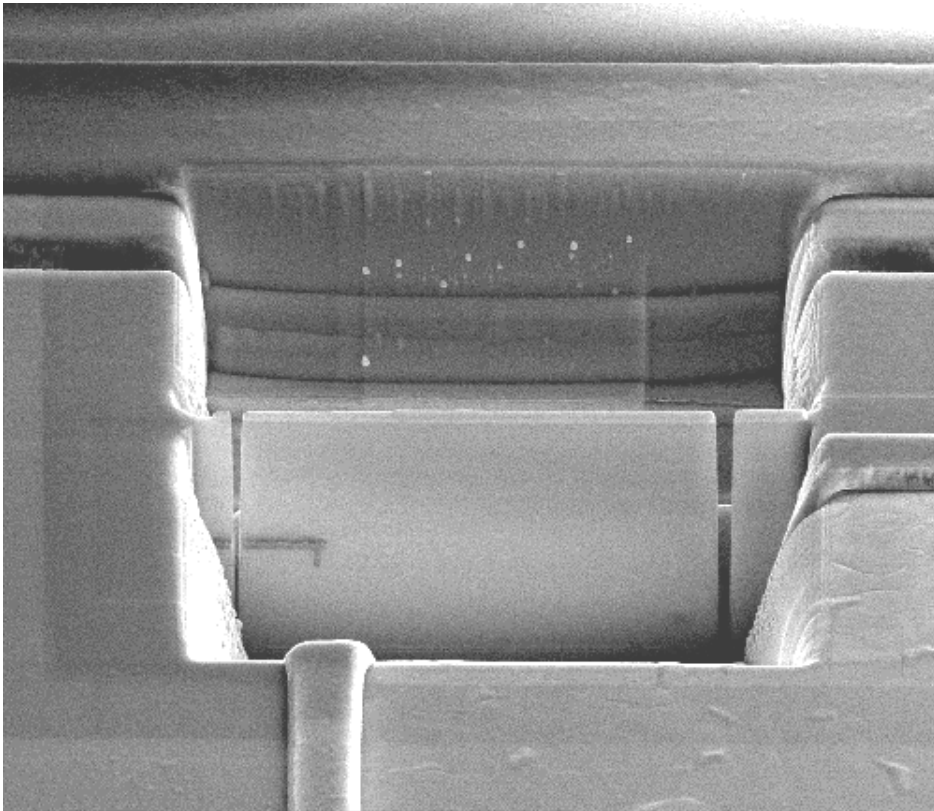
# FIB cut positioning - II



# Lamella preparation

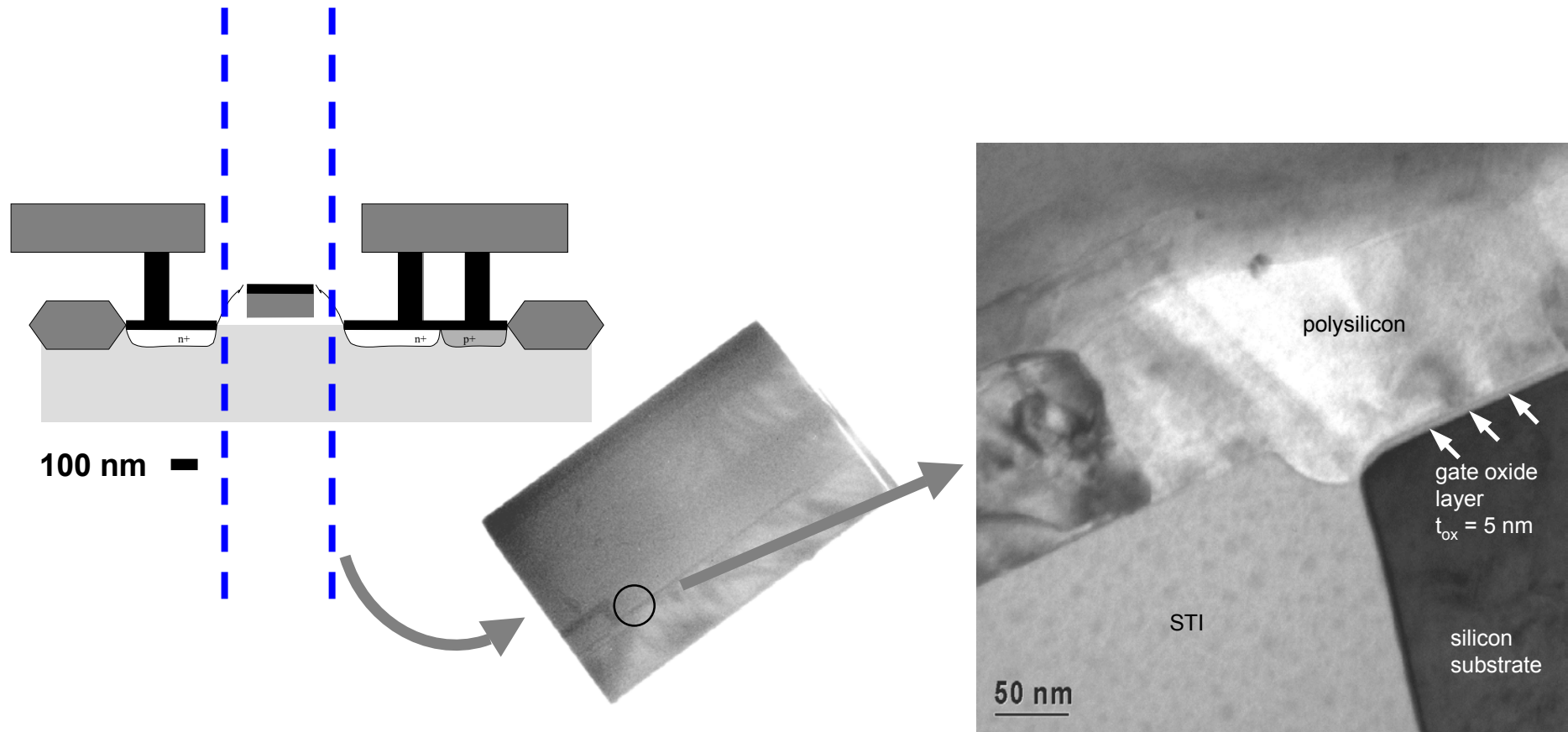


E-Beam	Spot	Mag	Det	FWD	Scan		5 $\mu$ m
10.0 kV	3	10.0 kX	CDM-E	4.719	H 11.77 s		



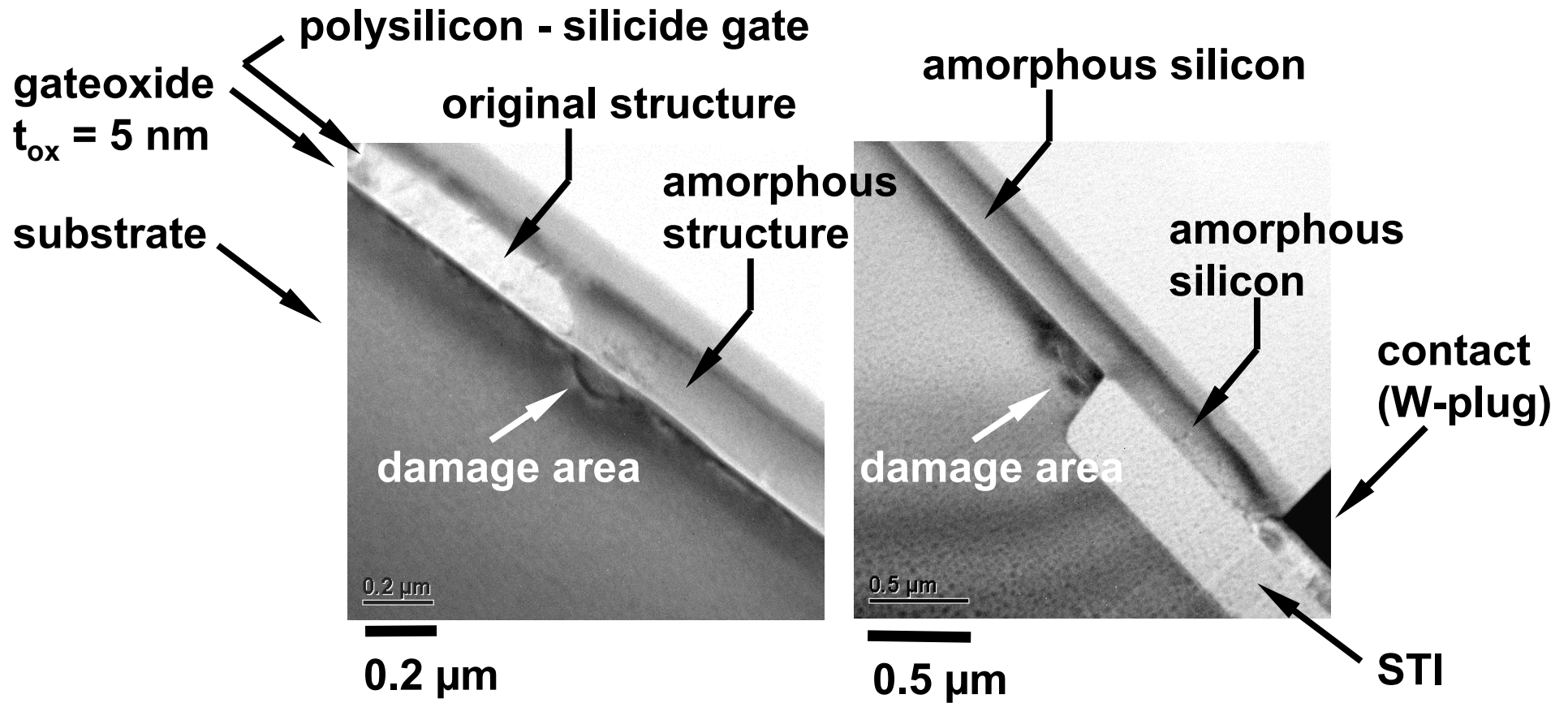
E-Beam	Spot	Mag	Det	FWD	Scan	HFW	5 $\mu$ m
10.0 kV	3	8.00 kX	CDM-E	4.670	H 6.34 s	38.0 $\mu$ m	

# First results

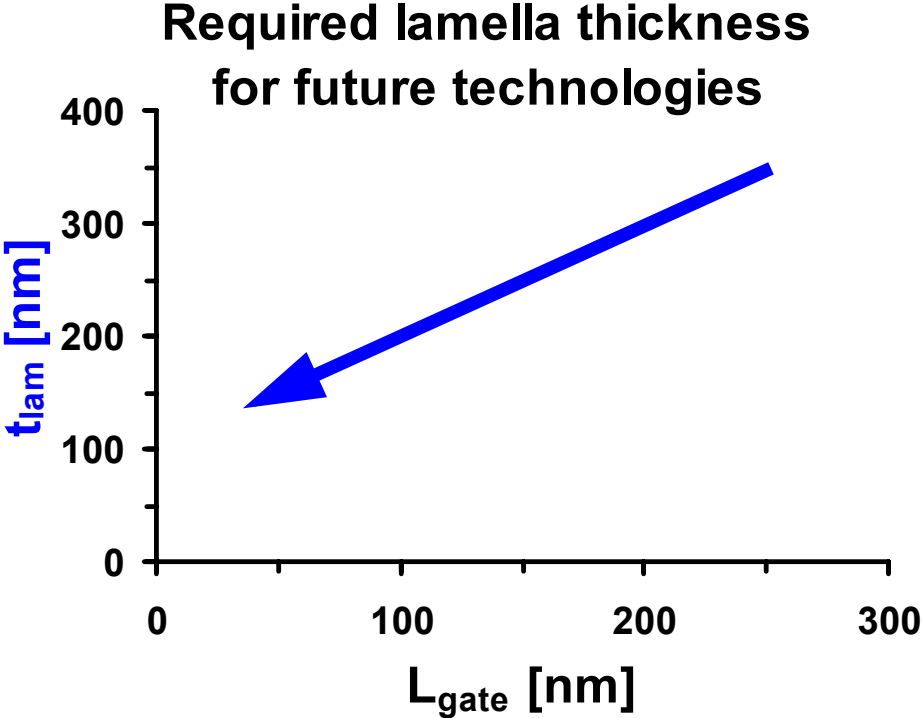
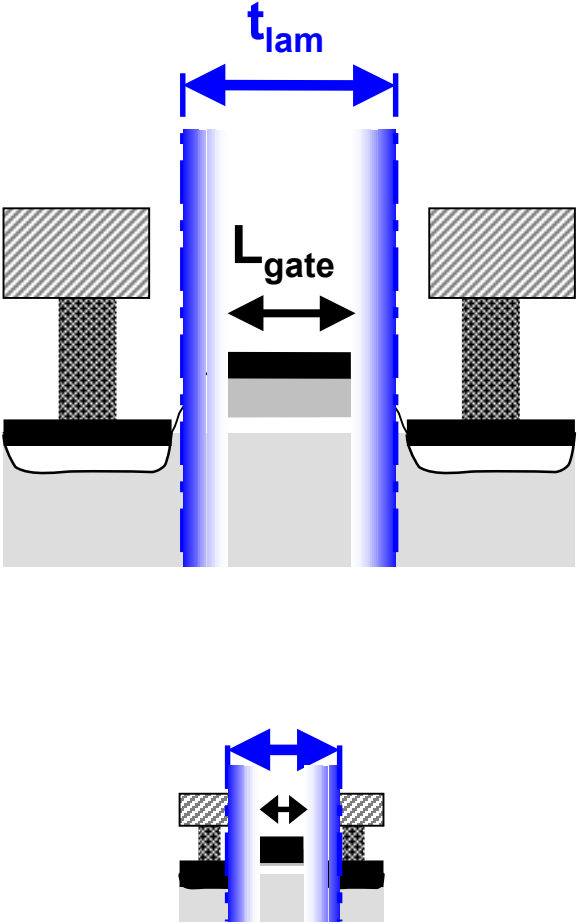


lamella thickness 400 - 500 nm

# Hard gate oxide breakdown



# Perspective



# Summary

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- ◆ **soft gate oxide breakdown microscopy challenge**
- ◆ **TEM most promising microscopy technique**
- ◆ **drawbacks of existing sample preparation methods**
- ◆ **demonstration of a new TEM lamella preparation approach providing**
  - ◆ **good surface quality**
  - ◆ **good visibility of the gate oxide**
  - ◆ **high chance to get the point of interest into lamella**
  - ◆ **less complex than SAPTEM**
  - ◆ **acceptable image quality in spite of the high lamella thickness (demonstrated for channel length of 250 nm)**
  - ◆ **lamella thickness reduces for future technologies**