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

Joachim Reiner, Philippe Gasser, Urs Sennhauser

EMPA (Swiss Federal Laboratories for Materials Testing and Research)

EMPA

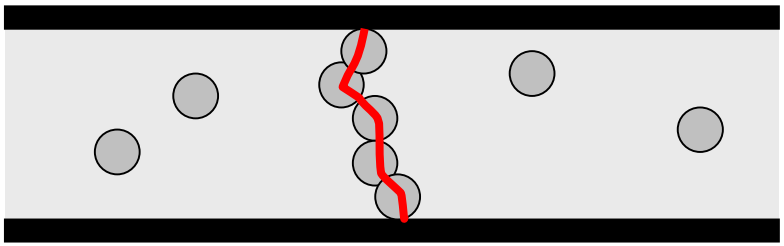
Outline

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

Theory of dielectric breakdown

Breakdown statistics

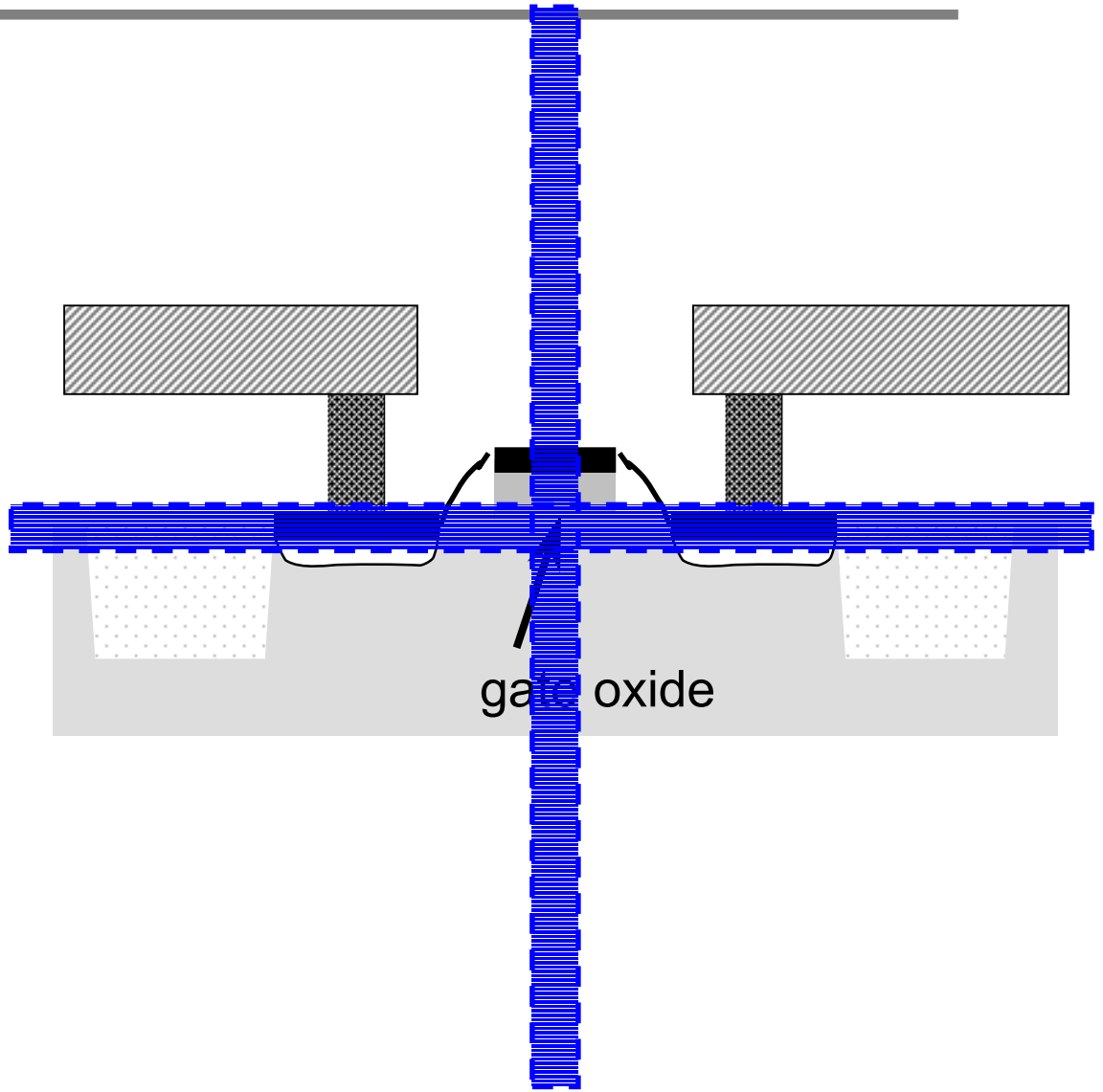
trap percolation model



Ref.: Degraeve et.al. IEDM 1995

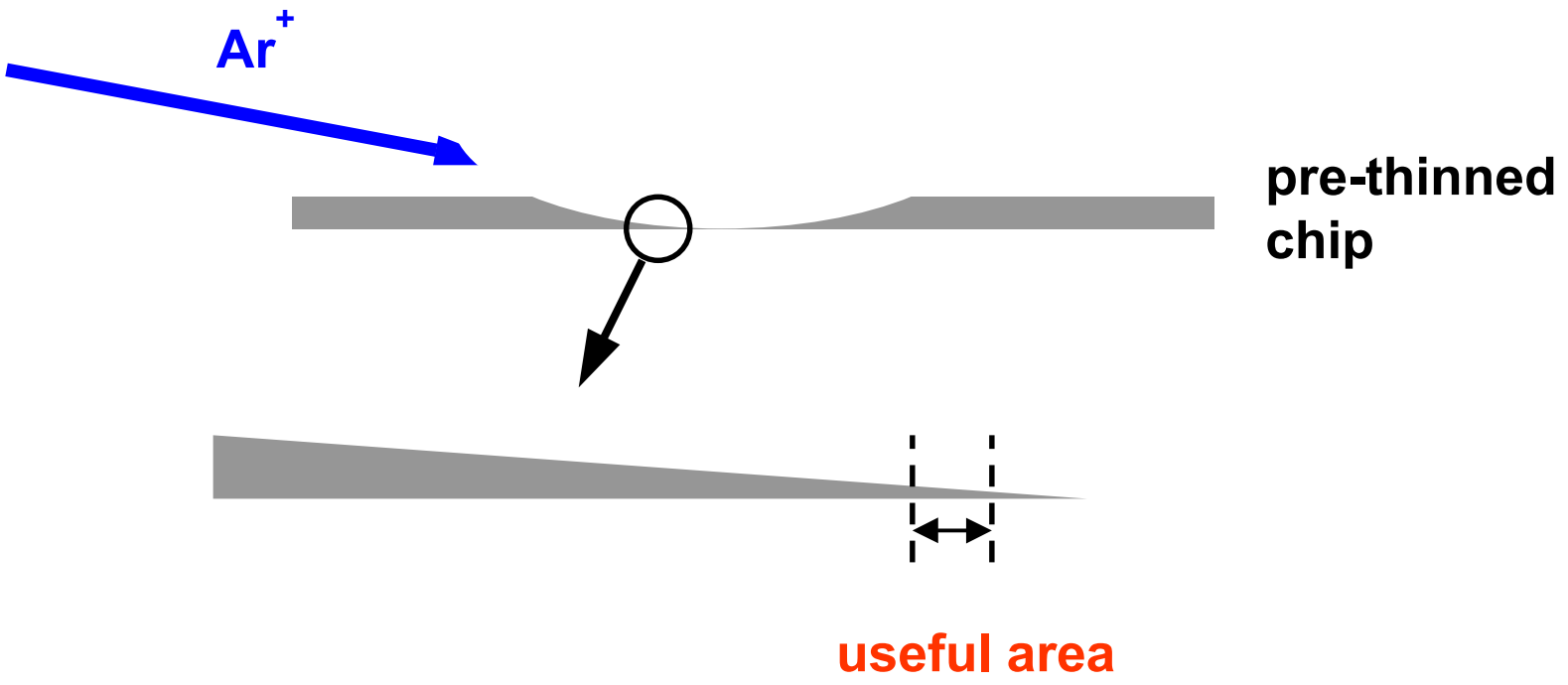
Microscopy challenge

- sBD site ≈ 1-10 nm
- visible structure change?
- TEM provides high-resolution non-destructive obervation
- TEM lamella preparation
- lamella thickness 100 nm



Horizontal lamella

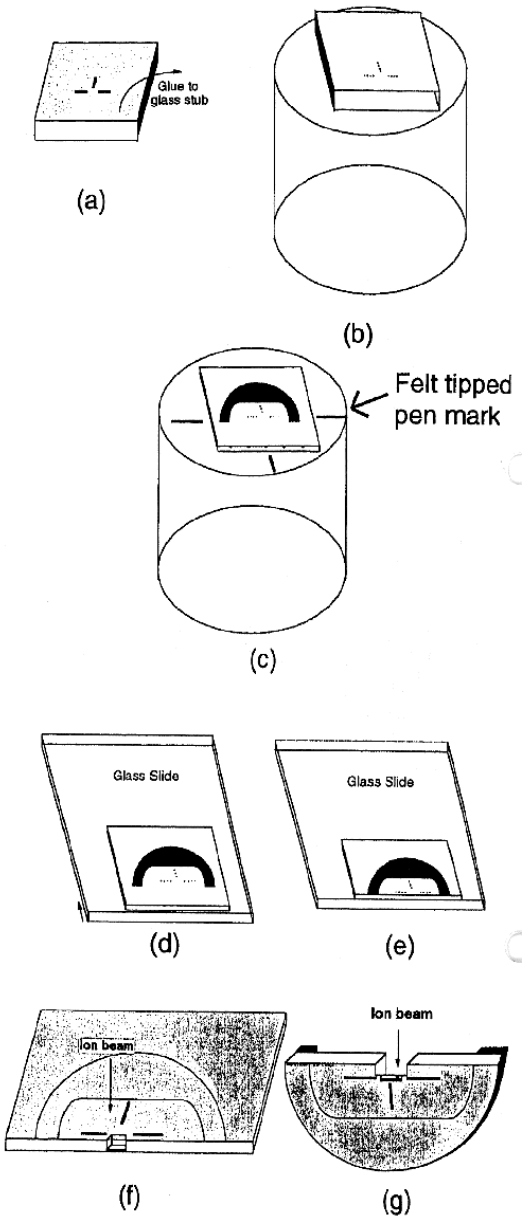
Ar ion beam thinning



Horizontal lamella - II

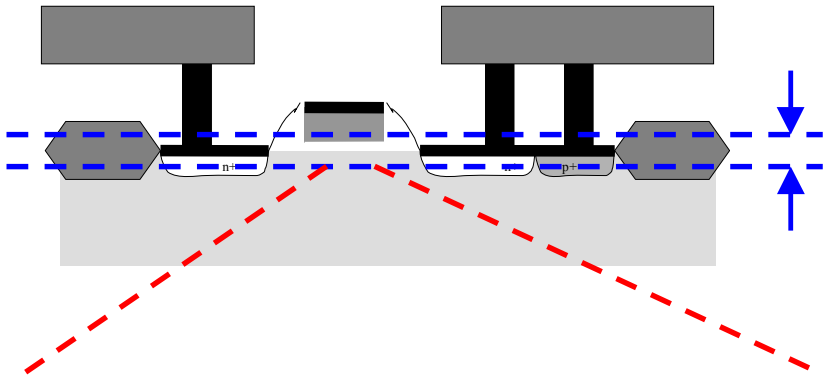
SAPTEM

- thinning of chip to ≈ 30 µm
- polish (vertically to chip surface) to ≈ 25 µm distance of the site
- bulk FIB cut
- planar FIB cut



Subramanian et.al., Motorola, ISTFA 1998

Horizontal lamella - III



TEM beam

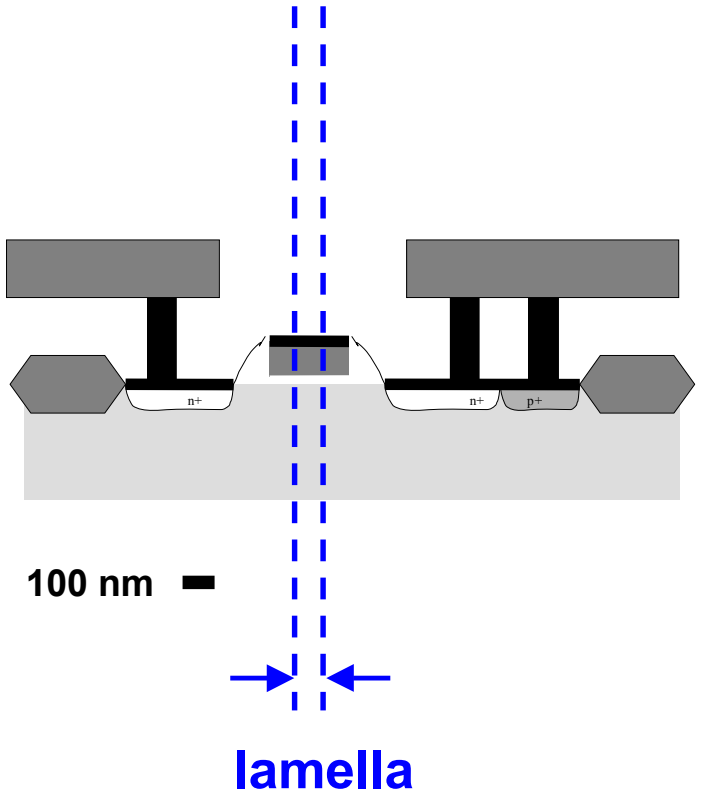
- irregularities of the polysilicon gate material visible in TEM image

poly-silicon

gate oxide

single crystalline silicon

Vertical TEM lamella using the FIB

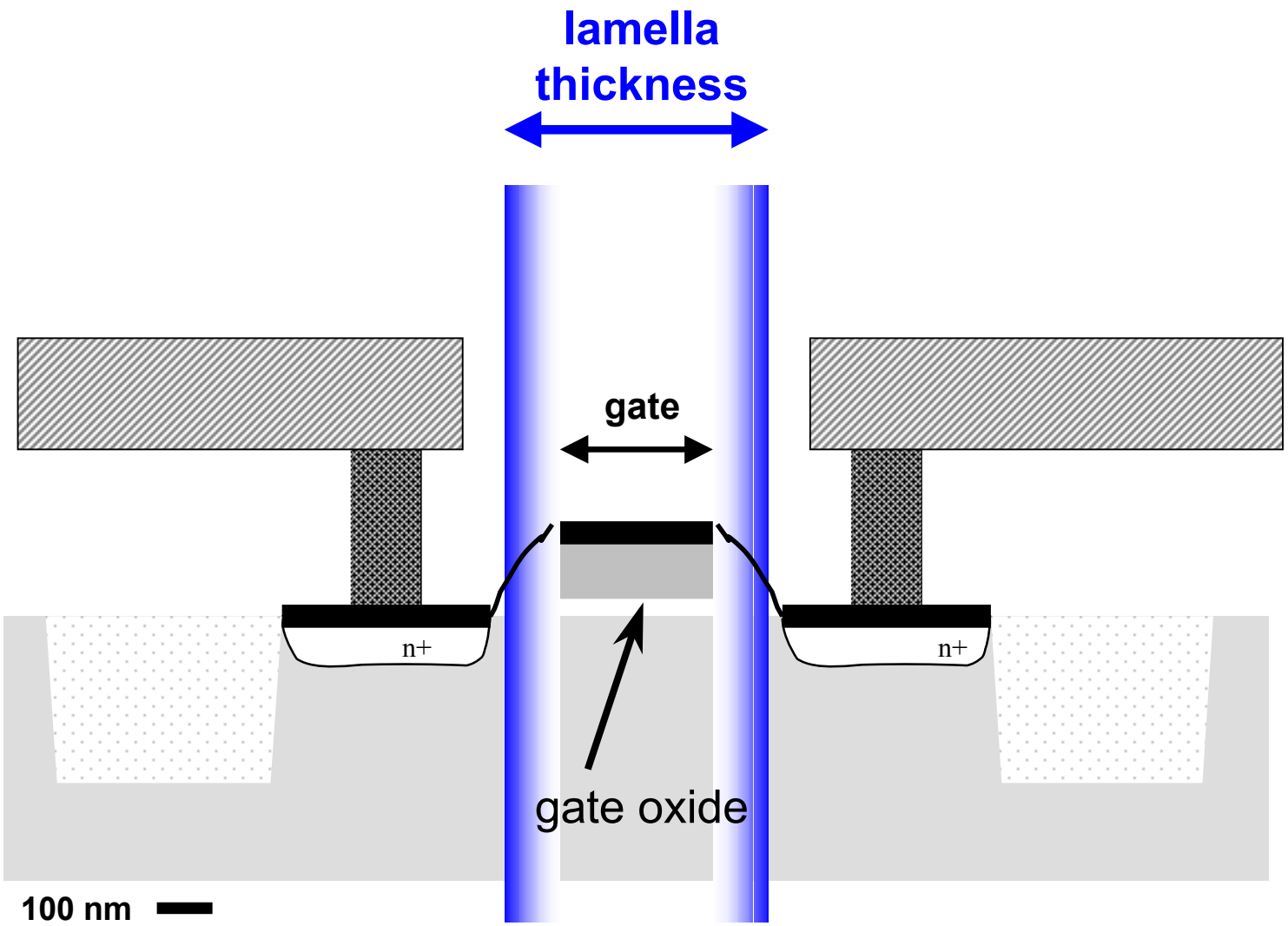


- TEM lamella thickness ≈ 100 nm
- defect localisation accuracy ± 500 nm
- 90 % probability to loose the damage site

TEM lamella preparation methods

	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 %

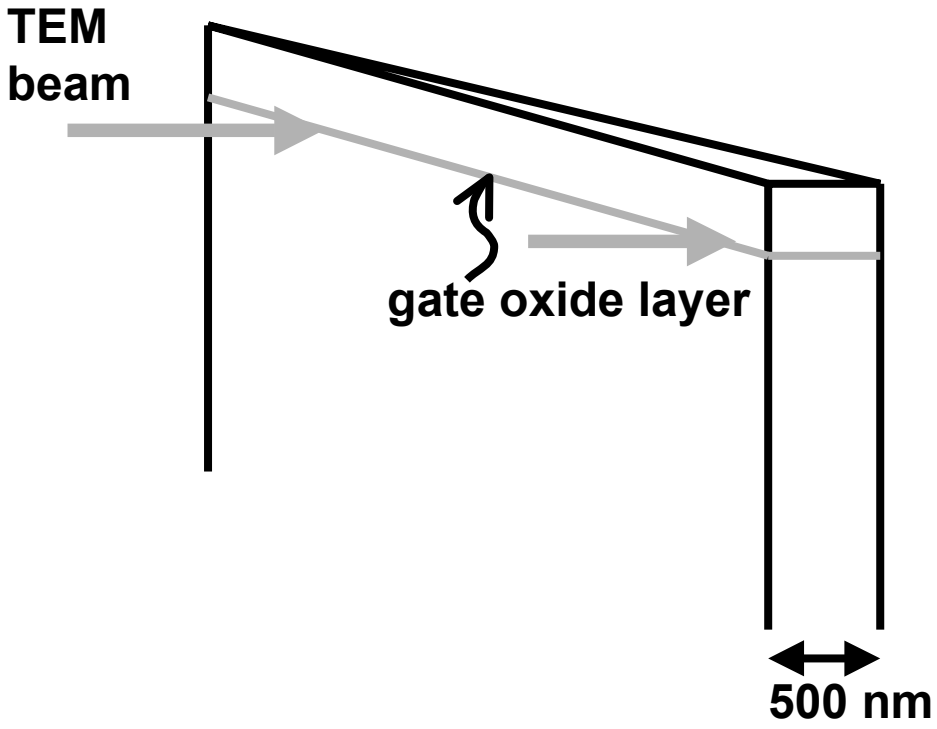
New approach



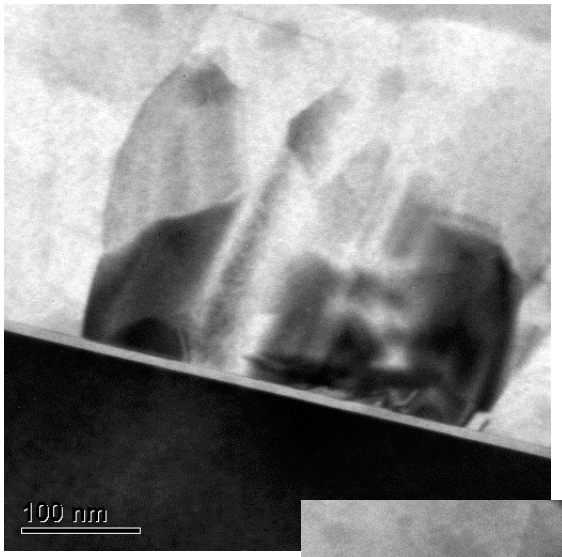
Problems to be solved

- is TEM still possible for lamella thickness >> 100 nm ?
- can the FIB cuts be positioned accurately enough ?

TEM of thick lamella

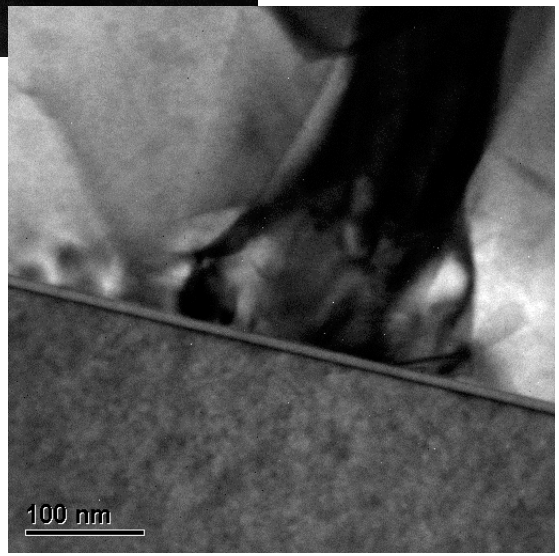


gate oxide



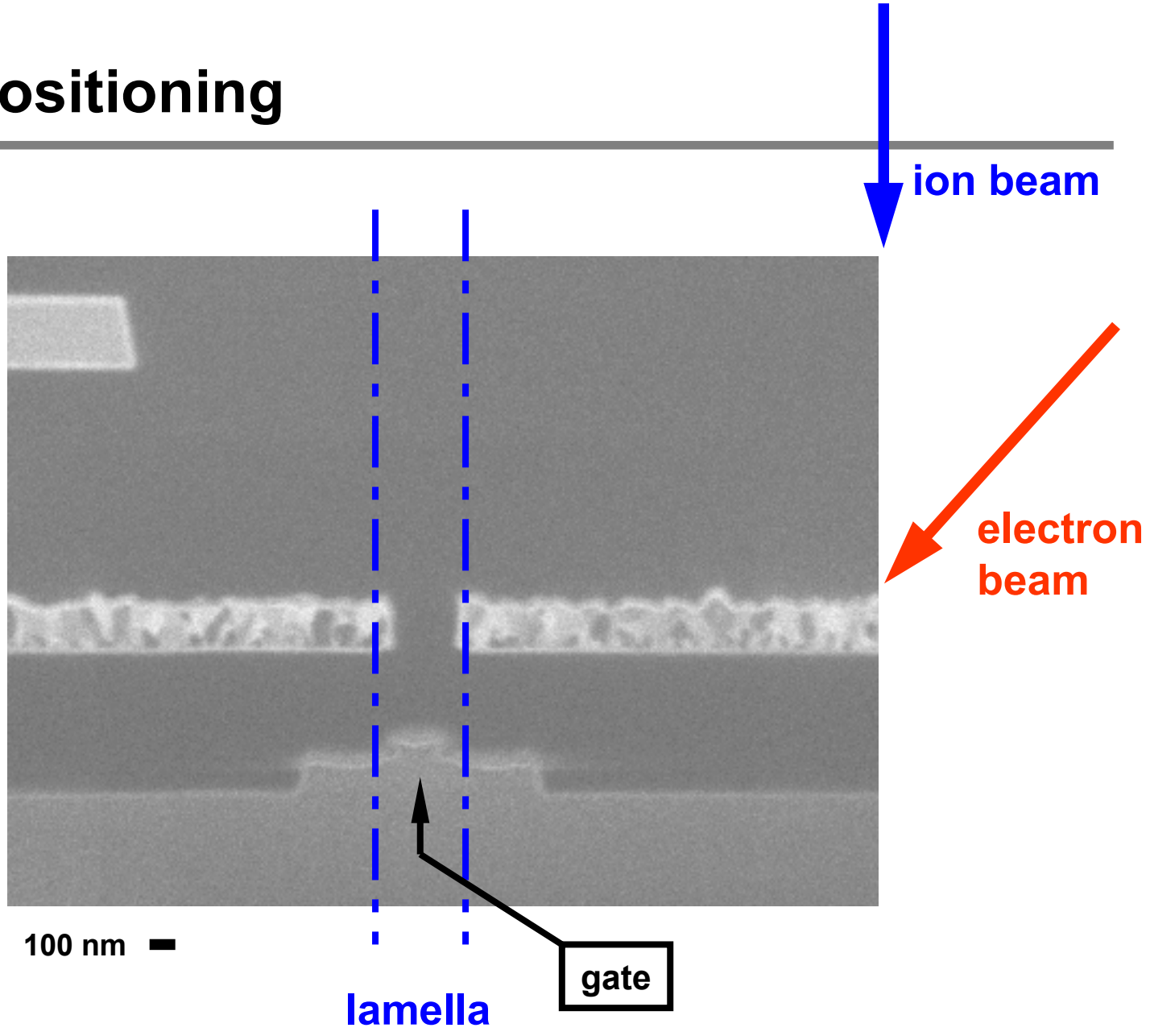
t = 100 nm

gate oxide

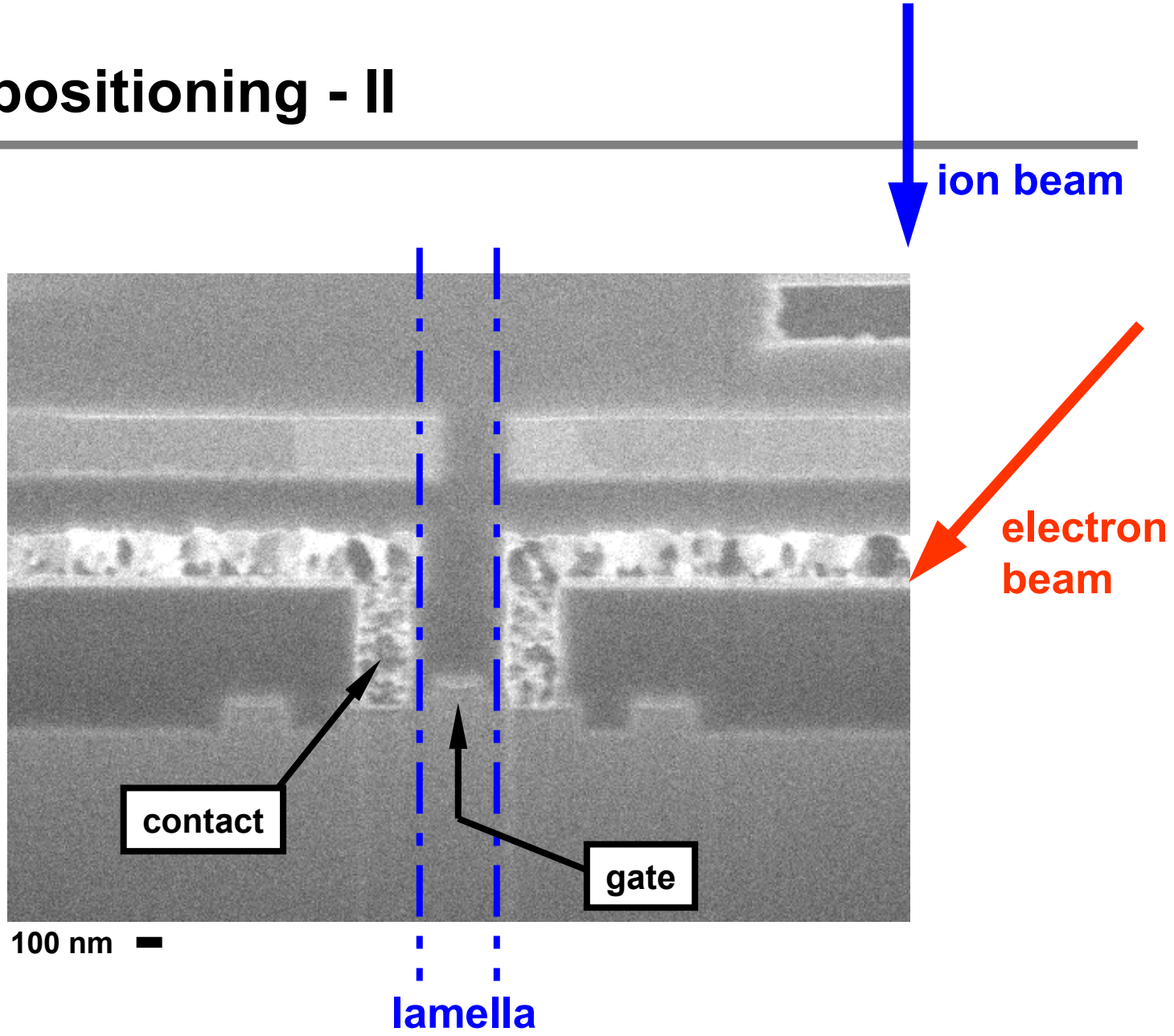


t = 500 nm

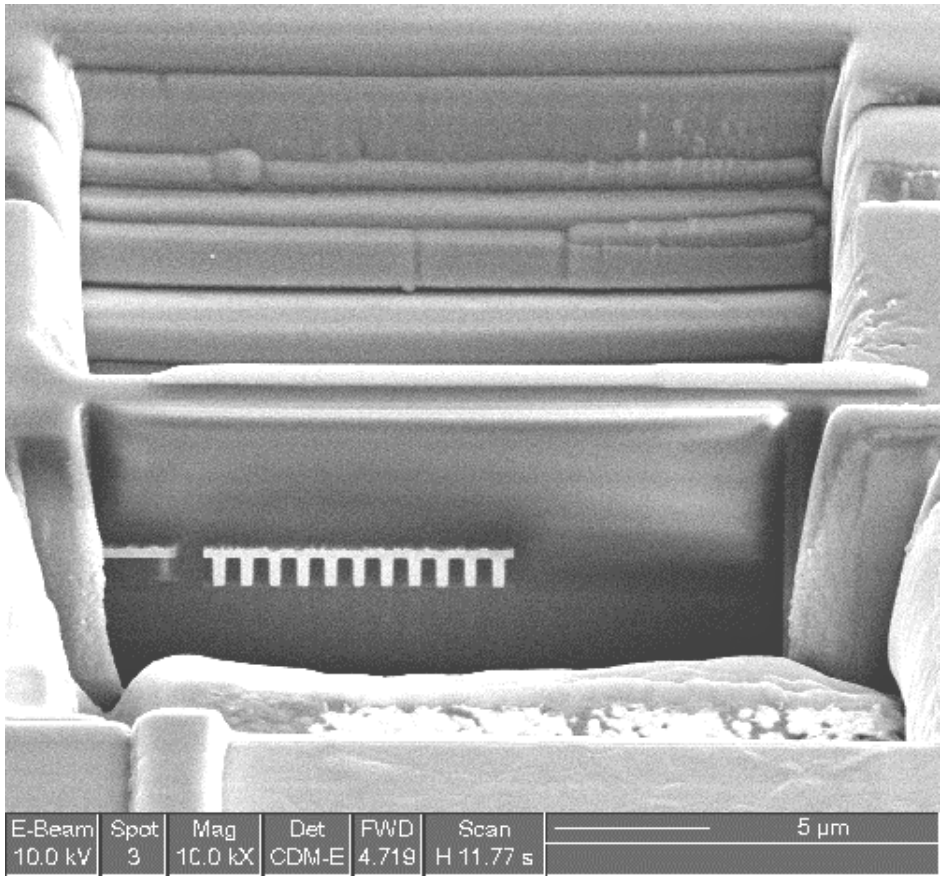
FIB cut positioning

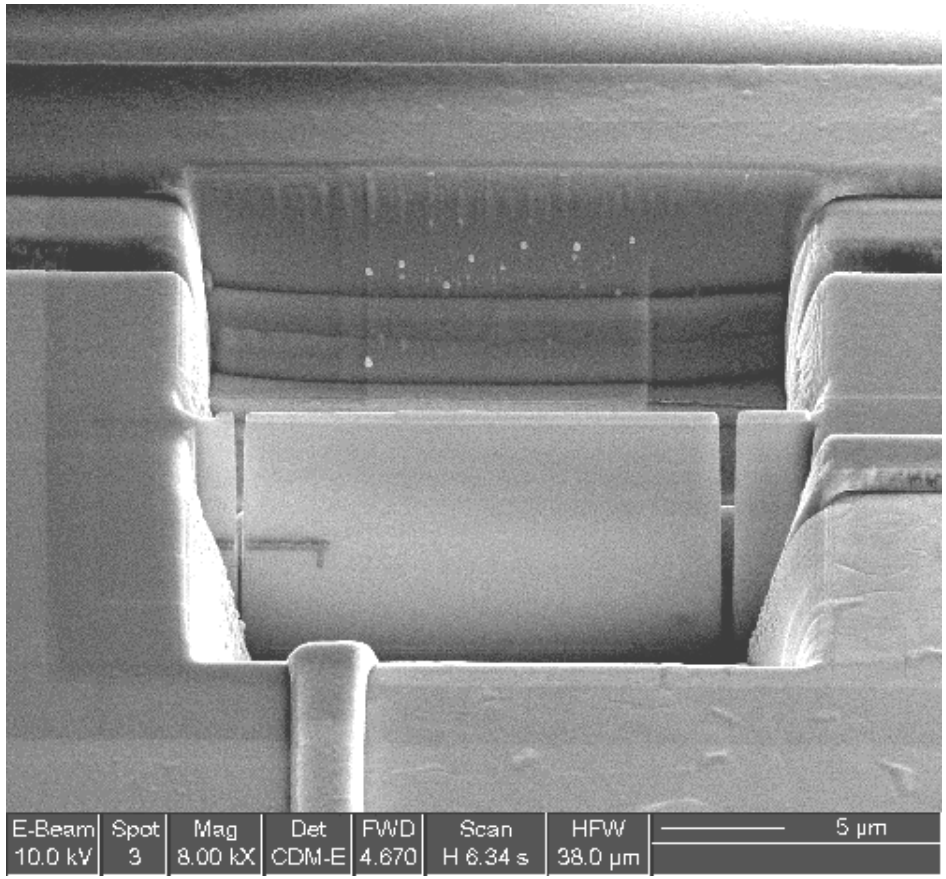


FIB cut positioning - II

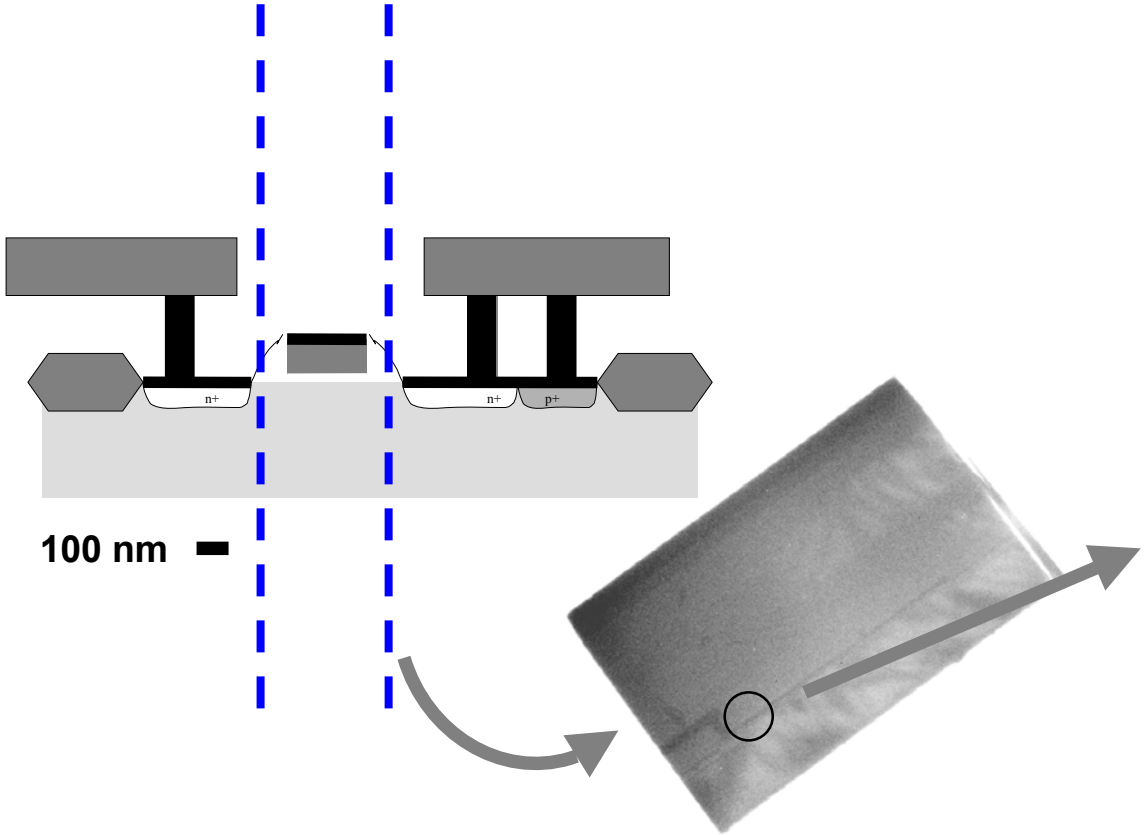


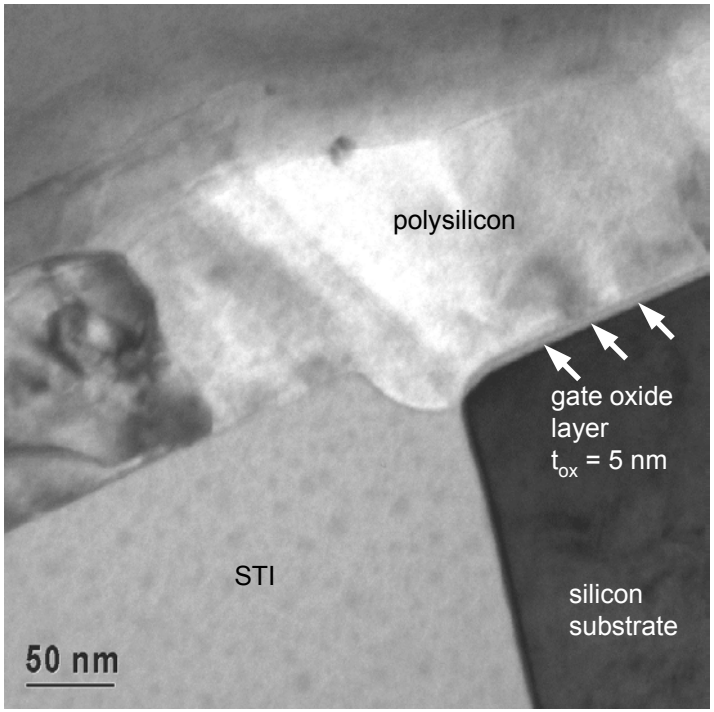
Lamella preparation





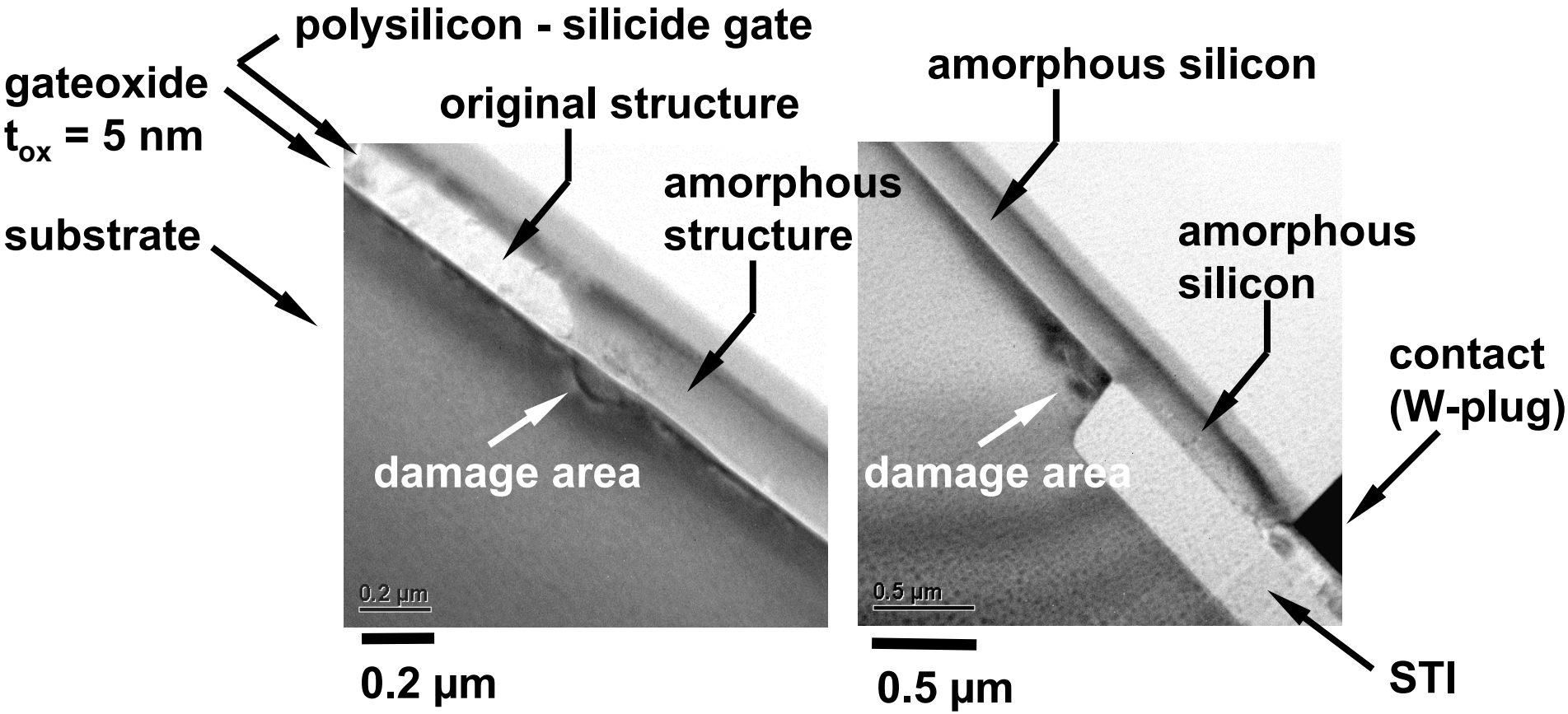
First results



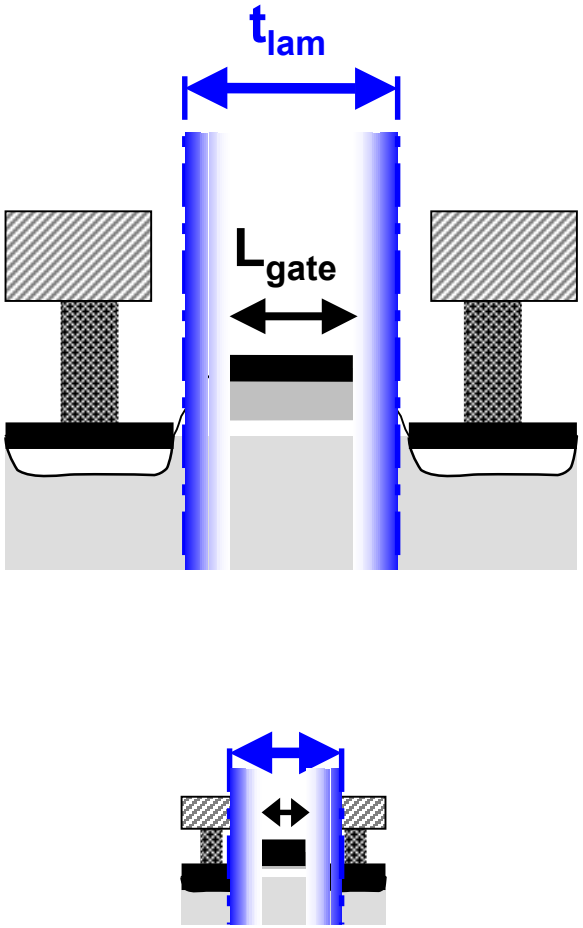


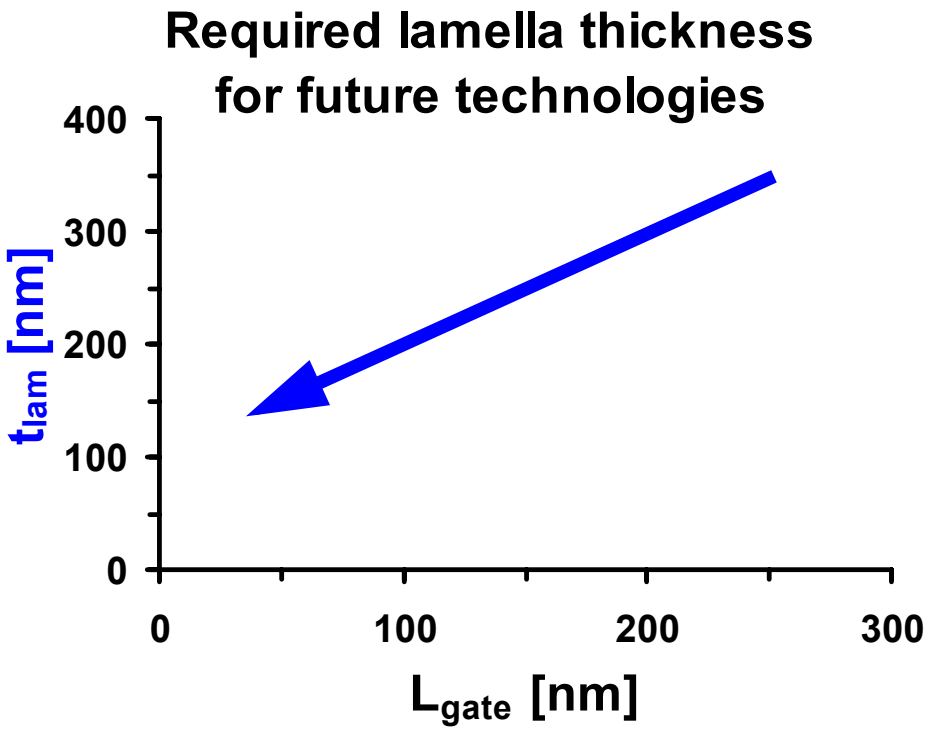
lamella thickness 400 - 500 nm

Hard gate oxide breakdown



Perspective





Summary

- 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