Direct Observation of Alloyed Contact Formation in Nanowire Cross-section

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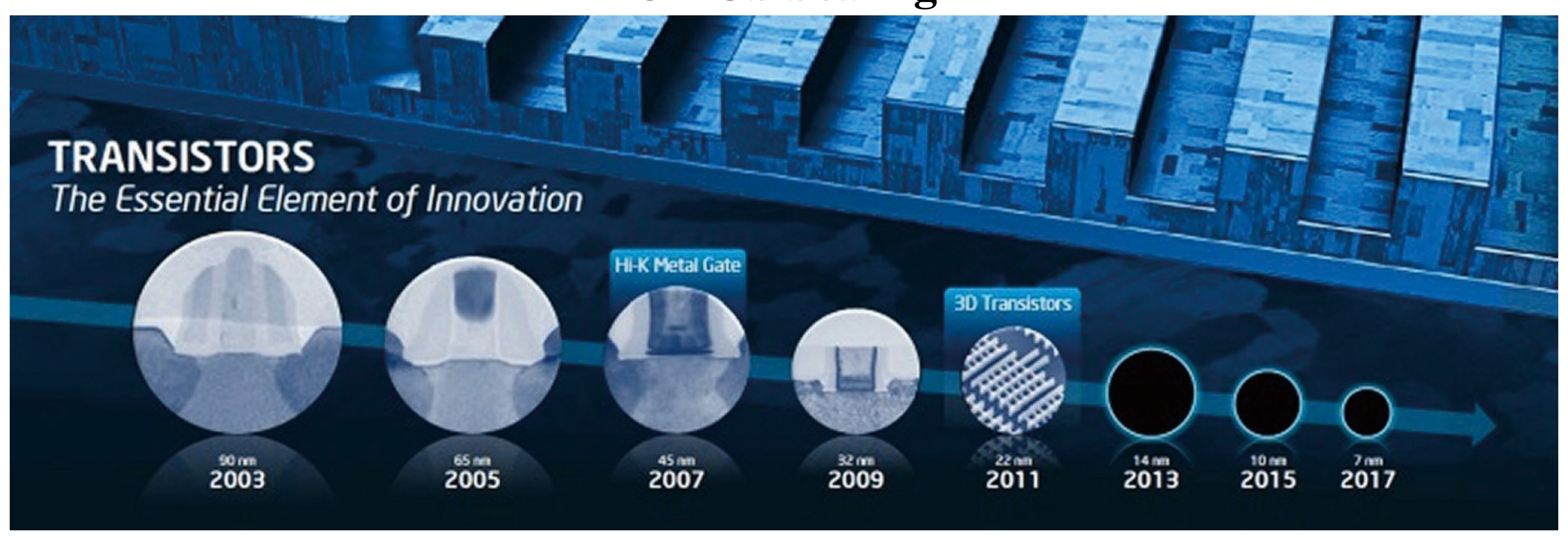
Motivation

CMOS Scaling

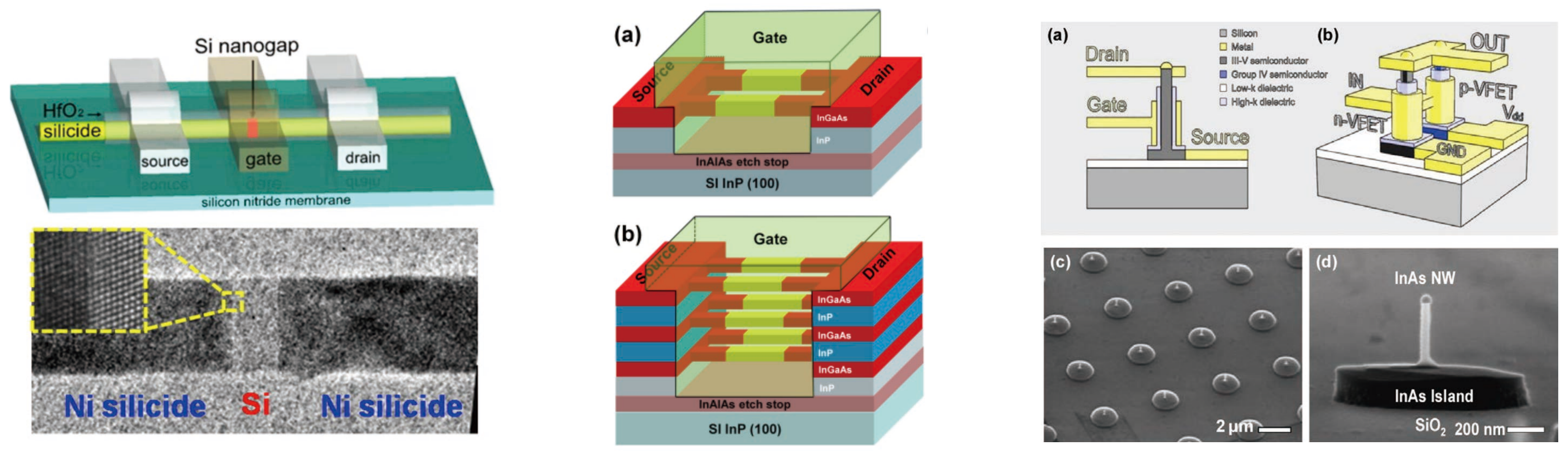


Intel Manufacturing Roadmap 2003-2017

The metal-semiconductor contact in ultra-scaled devices is one of the most critical factors limiting device performance.

Opportunities and Challenges

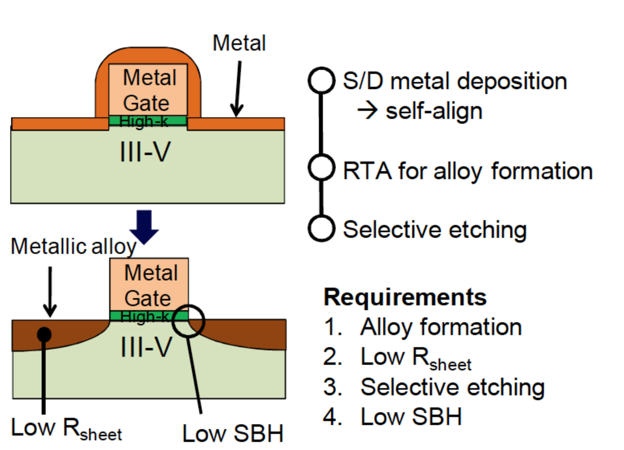
Nanowire Transistors



Tang and et al. *Nano Letters*, 12, 3979, **2012**   Gu and et al., Electron Devices Meeting (IEDM), **2012**   Dayeh and et al. *Nano Today*, 4,4, 347, **2009**

- Nanowires are promising building blocks for future nanoscale electric devices.
- High electron-mobility III-V nanowires hold great potential in sub-7 nm MISFETs.
- Metal-semiconductor alloyed contact has not been evaluated in nanowire cross-sections, which will be critical for a self-aligned gate-first process.

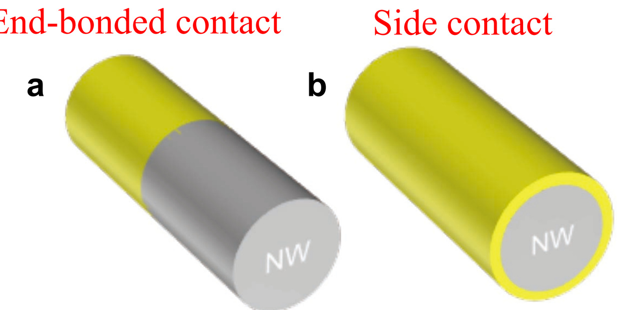
Self-aligned Contact



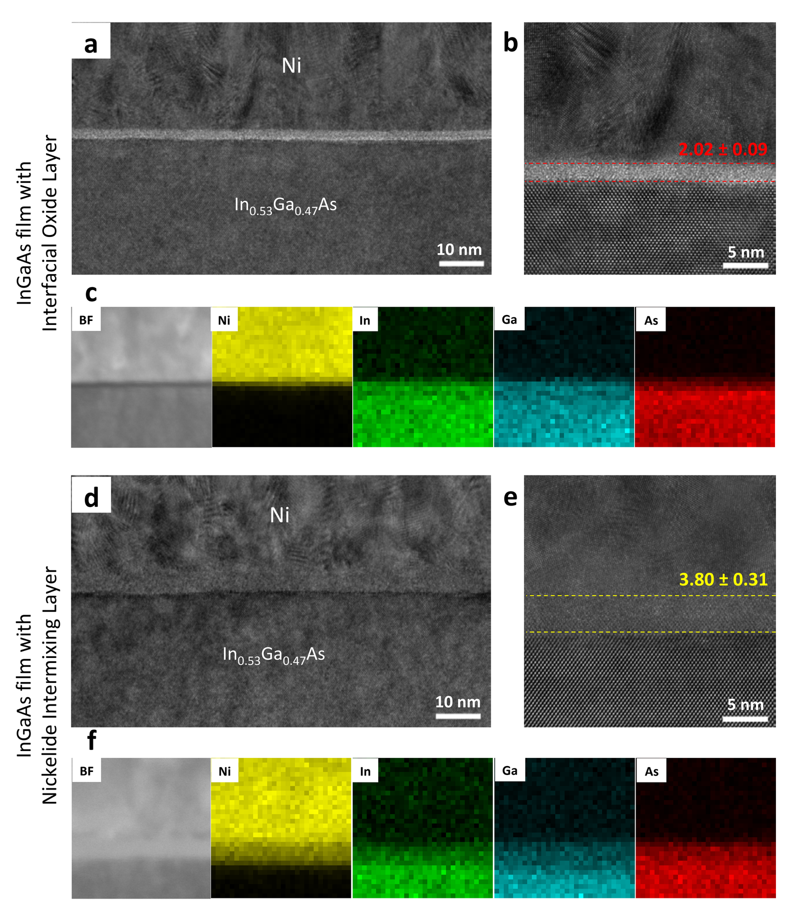
S. Kim et al., Electron Devices Meeting (IEDM), **2010**

Contacts in Nanowire Geometry

End-bonded contact   Side contact

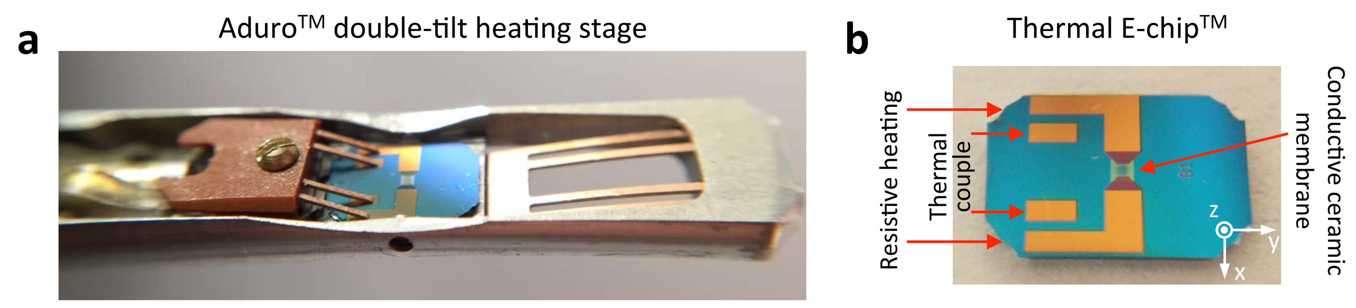


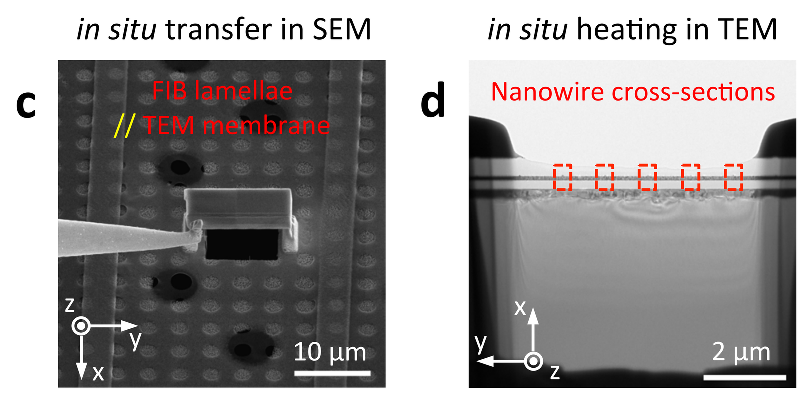
Metal-semiconductor Interfaces



Integration of FIB Lamellae on *in situ* Heating TEM Platform

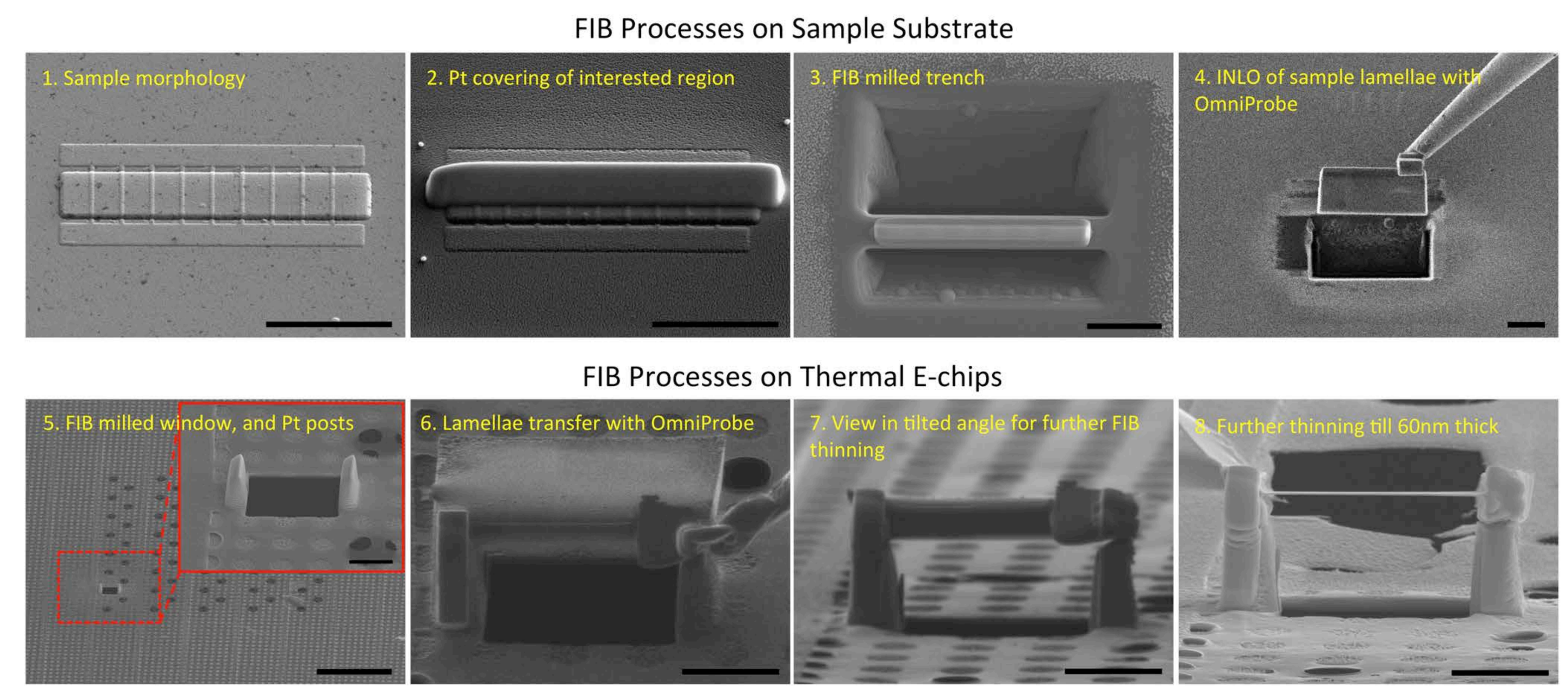
in situ TEM platform





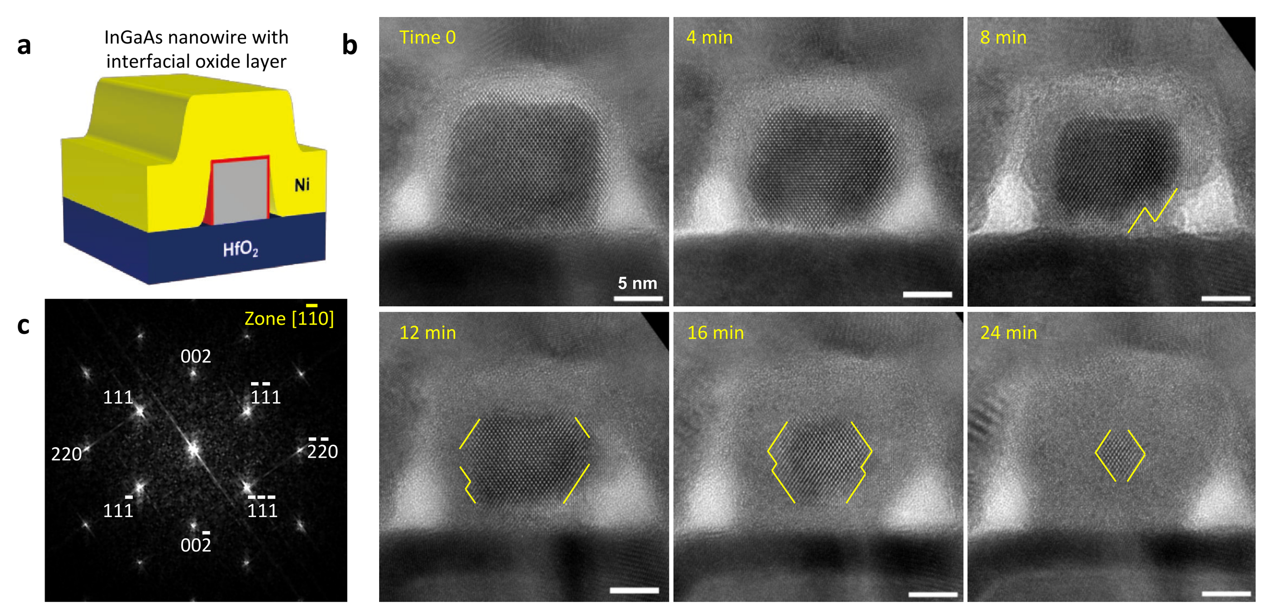
Aduro™ heating stage:
- Ultra fast temperature stabilization
- Low image drift
- Double tilt α and β
- Fast thermal ramp / quench speed

Sample transferring procedures

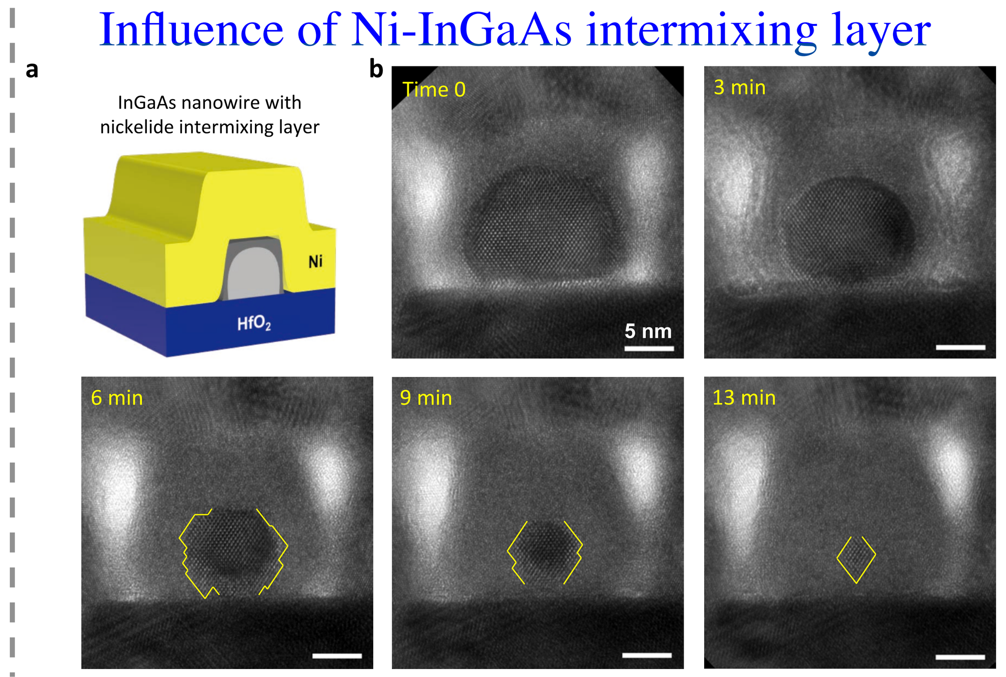


Interface-determined Reaction Kinetics

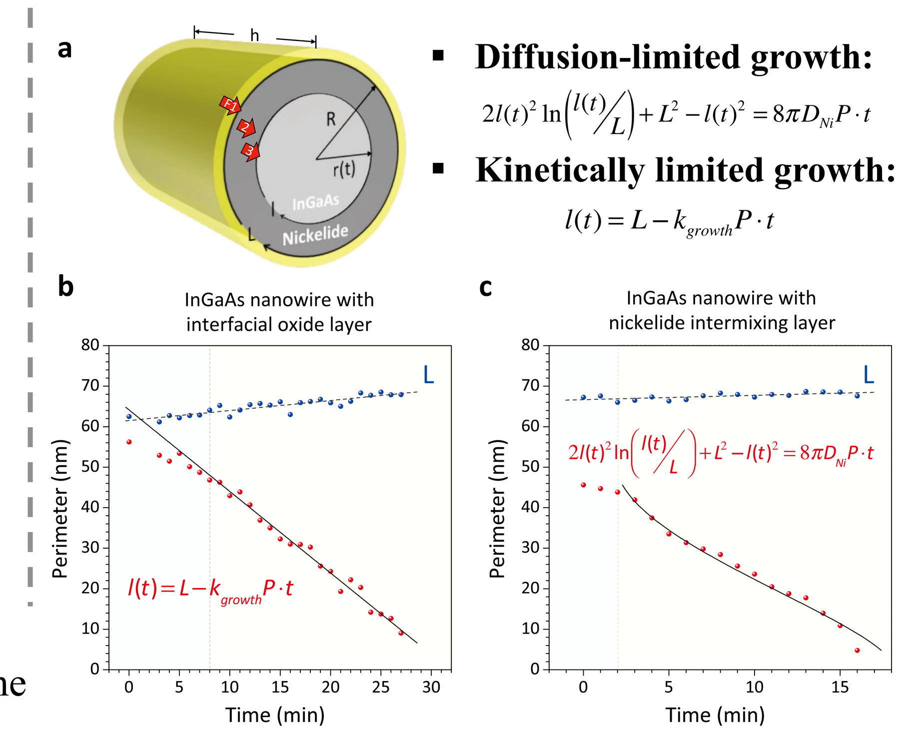
Influence of InGaAs surface oxide layer



Influence of Ni-InGaAs intermixing layer



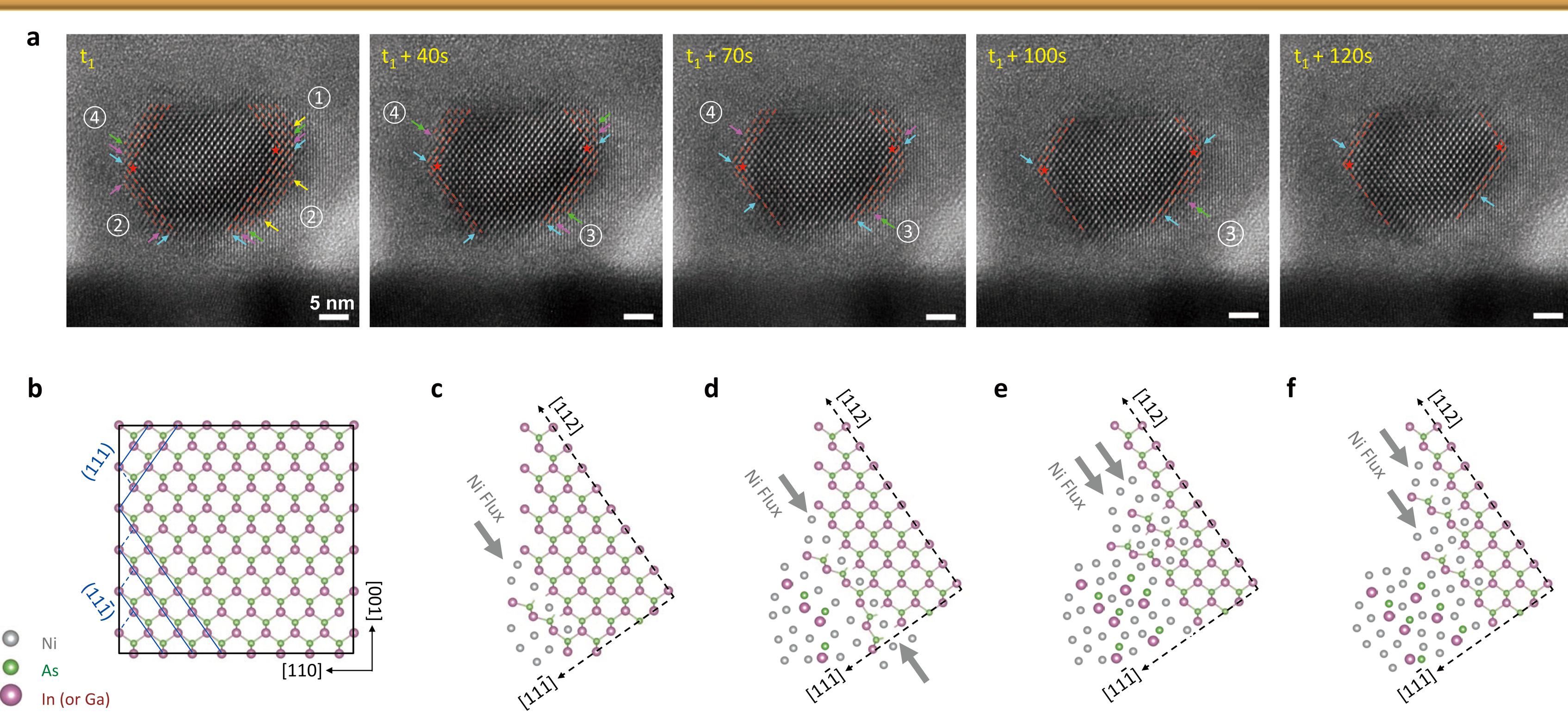
Models of radial contact alloying



- **Diffusion-limited growth:** $2l(t)^2\ln\left(\frac{l(t)}{L}\right)+L^2-l(t)^2=8\pi D_{Ni}P\cdot t$
- **Kinetically limited growth:** $l(t)=L-k_{growth}P\cdot t$

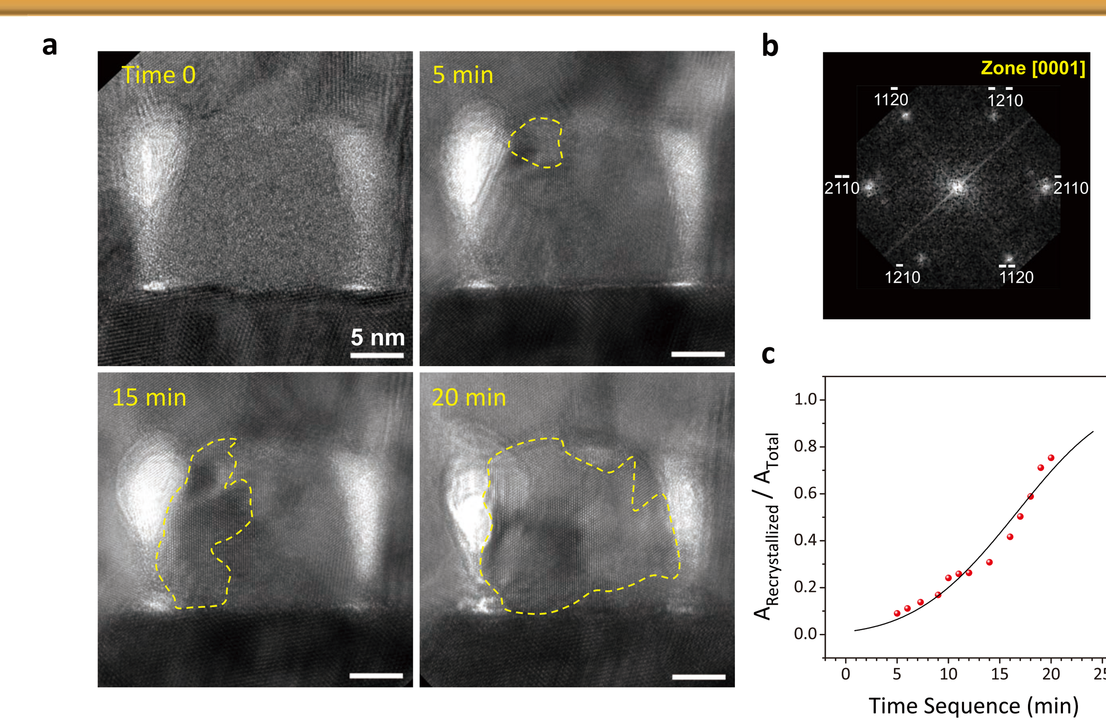
- At temperatures above 180°C, the nanowire cross-section experiences a solid-state reaction and forms amorphous $Ni_xIn_{0.53}Ga_{0.47}As$ (x<2).
- The reaction is kinetically limited when there exists an interfacial oxide layer, otherwise, it changes to a diffusion-limited growth with the presence of an intermixing layer between Ni and InGaAs during metal deposition.

Ledge Formation and Movement



- Nickelide reacts in a layer-by-layer manner proceeding by ledge movements on {111} facets along <112> directions.

Recrystallization



- The amorphous $Ni_xIn_{0.53}Ga_{0.47}As$ (x<2) phase regrew into a single crystalline $Ni_2In_{0.53}Ga_{0.47}As$ phase at temperatures above 375 °C by additional incorporation of Ni adatoms from the contact reservoir.

Renjie Chen, Katherine L. Jungjohann, William M. Mook, John Nogan, and Shadi A. Dayeh "Atomic Scale Dynamics of Contact Formation in the Cross-section of InGaAs Fin/Nanowire Channels" *Nano Letters*, accepted, **2017**

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