Ni_2Si and NiSi Formation by Low Temperature Soak and Spike RTPs

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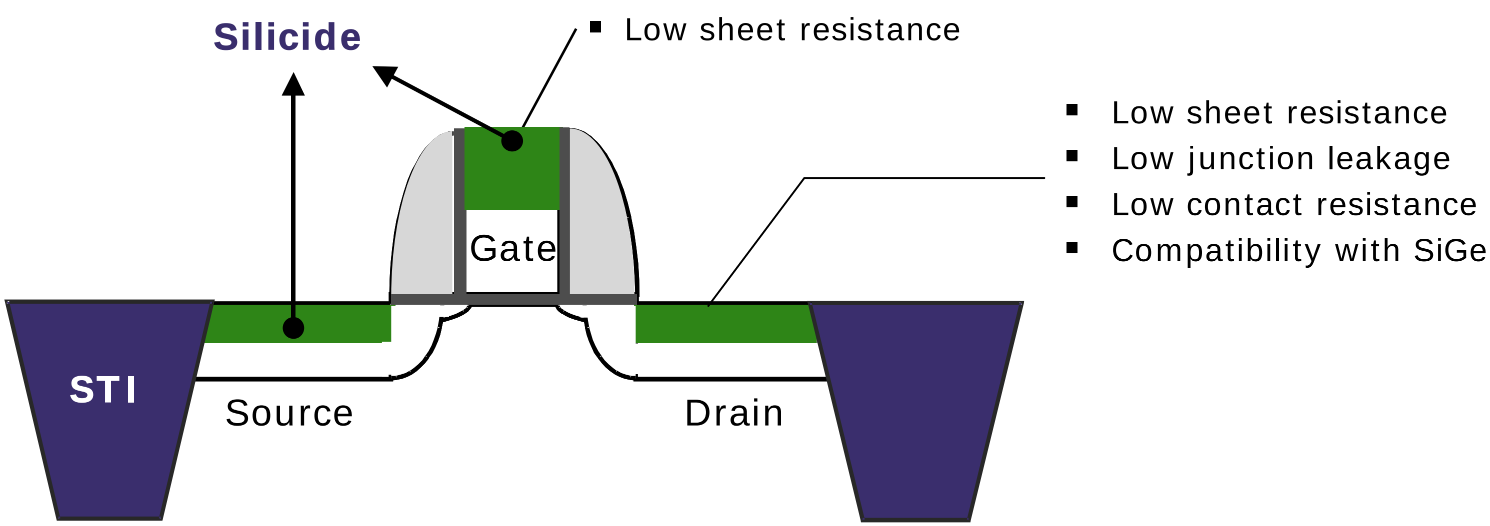
Outline

- Background and Motivation
- Experimental Procedure
- Results
  - Soak RTP at 270 °C: Ni_2Si growth
  - Soak RTP at 300 °C: Ni_2Si-NiSi transformation
  - Spike RTP
- Effective Time Analysis
  - Comparative study for spike and soak anneals
- Summary and Conclusions

Requirements in Self-aligned Silicide Process



	$TiSi_2$ (C54)	$CoSi_2$	NiSi
RTP 1	600-800°C (C49)	400-600°C (CoSi)	**250-350°C (Ni_2Si)**
RTP 2	700-900°C (C54)	650-850°C ($CoSi_2$)	**400-500°C (NiSi)**
Adv.	▪ Modest Si consumption ▪ Good thermal stability (~900°C)	▪ Good thermal stability (~1000°C)	▪ **No line-width effect** ▪ **Lower Si consumption** ▪ **Miscibility with NiGe**
Disadv.	▪ Line-width dependence → scaling issues ▪ Gate to S/D silicide bridging	▪ Larger Si consumption → not optimal for shallow junctions	▪ **Low thermal stability (~600°C)** ▪ **Increased temperature sensitivity for formation**

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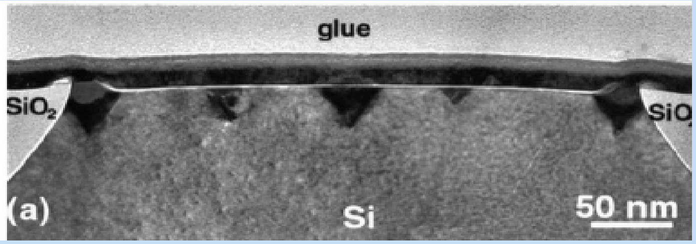
Challenges of Integrating NiSi

- Thermal instability
  - NiSi is stable only up to ~700 °C
  - Film agglomeration
  - Post-silicide processes will not exceed 450°C for the back-end.

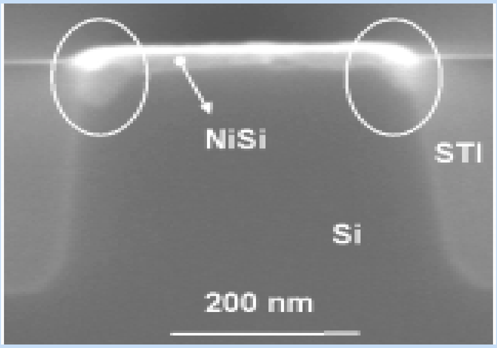
Source: A.S.W.Wong et al, APL, 81, 5138 (2002)

- Defect formation
  - Epitaxial $NiSi_2$ formation
  - Careful surface preparation is needed



Source: V. Teodorescu et al, JAP, 91, 167 (2001)

- Excessive silicidation
  - At narrow gates, source and drain regions
  - Accidental fully silicidation of gates
  - Need to Limit the silicide reaction at low temp



Source: A.Lauwers et al, Microelectronic Eng. 76, 303 (2004)

Two-step RTP Process for NiSi

- Gate stack formation
- Ni/TiN dep
- **RTP1 at <300°C**
  - Ni-rich silicide

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- Selective wet strip

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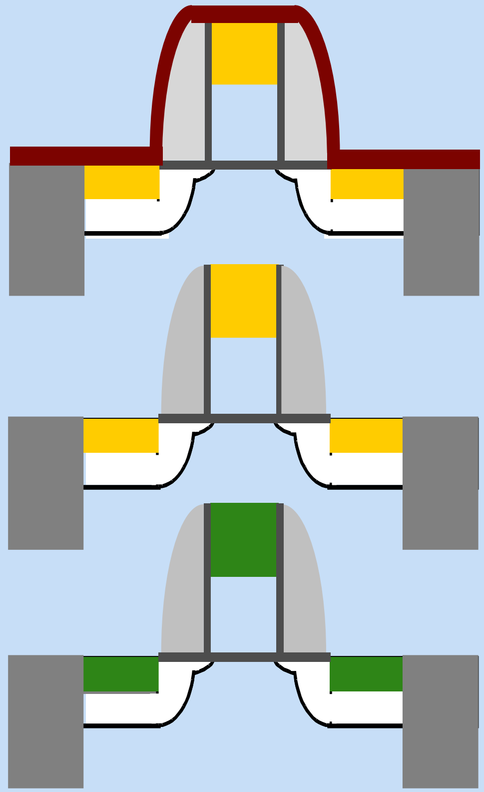
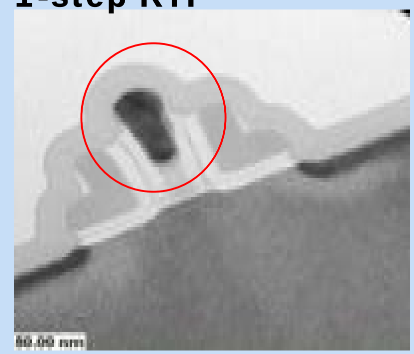
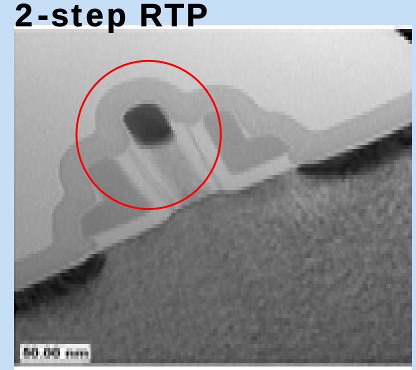
- **RTP2 at 400-500°C**
  - Low resistance NiSi



1-step RTP



2-step RTP



Source: J.P. Lu et al., IEDM 2002

- 2-step anneal process includes:
  - RTP1: to control the nickel diffusion at lower temperatures (250~350°C)
  - RTP2: to form low resistance NiSi at higher temperatures (400~500°C)
- Effective in preventing the excessive silicidation at the narrow gate/source/drain.

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Motivation for This Work

- RTP1 is crucial in limiting the Ni diffusion and the silicidation, since it occurs when the excess Ni is present
- Low temperature regime of the reaction between Ni and Si needs better understanding
- Low temperature spike RTP for NiSi process can provide advantages by further controlling thermal budget

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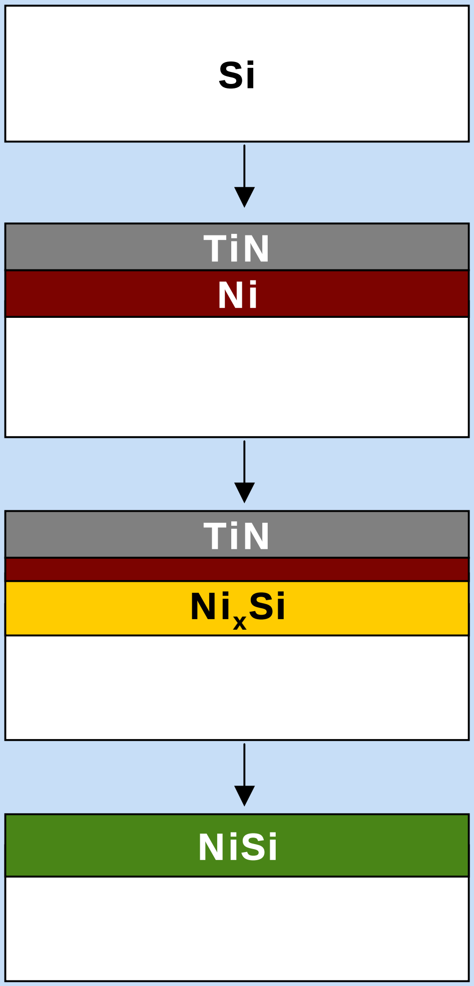
Experimental Details



- Substrate: 8” Si (001) wafers
- Pre-clean: HF-last
- 10nm-Ni/10nm-TiN deposition:
  -Applied Endura ALPS Ni PVD
- RTP1 Silicidation:
  -Applied Centura Radiance*Plus* RTP
  Soak anneal: 270, 300°C, 1~300 sec
  Spike anneal: 300~400°C
- Strip TiN cap, unreacted Ni
- Analysis: Rs, XRD, XRR, TEM

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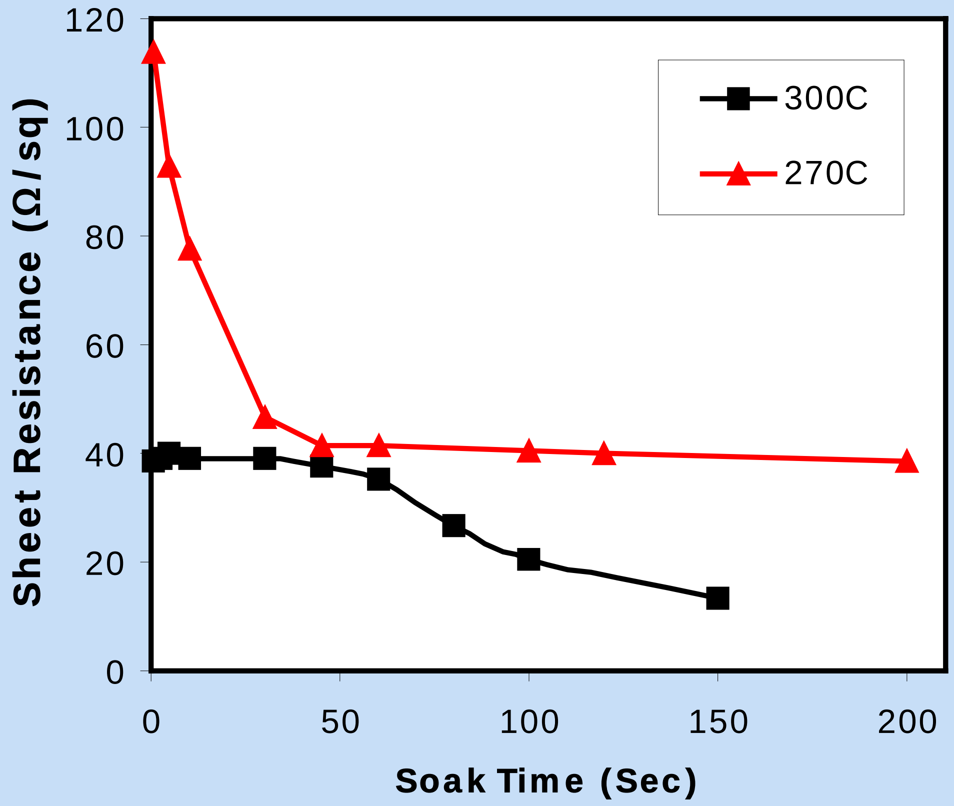
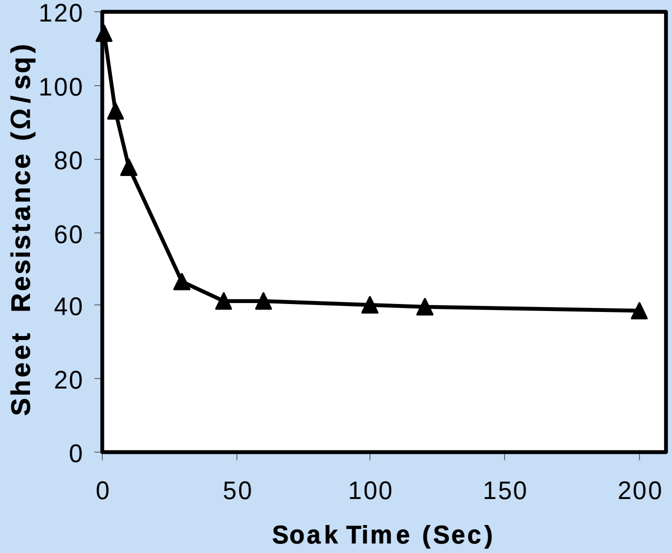
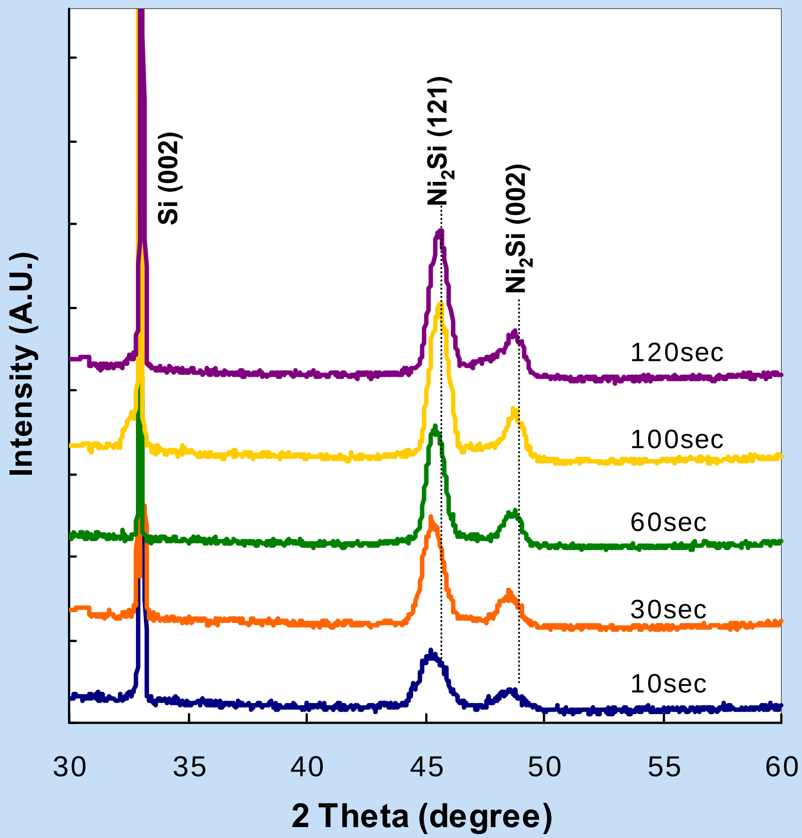
Rs After Soak RTP at 270 and 300°C



- At 270 °C, Rs decreases, then saturates after 45 sec.
- At 300 °C, Rs drops after 60 sec, which is associated with the transformation into NiSi

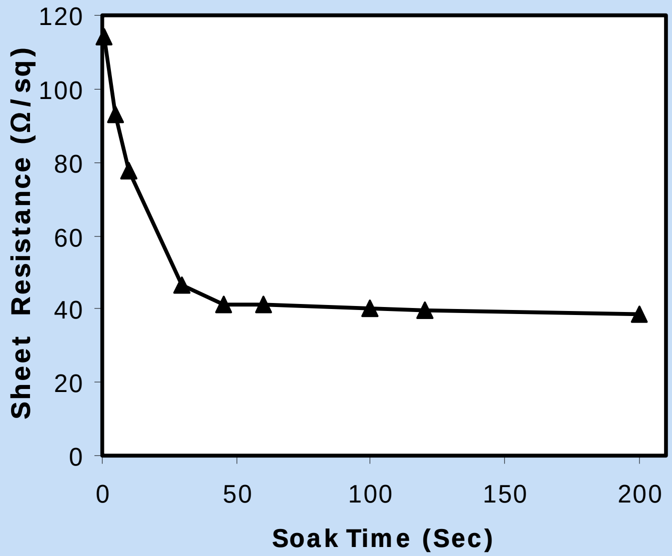
XRD Spectra from the 270°C Samples

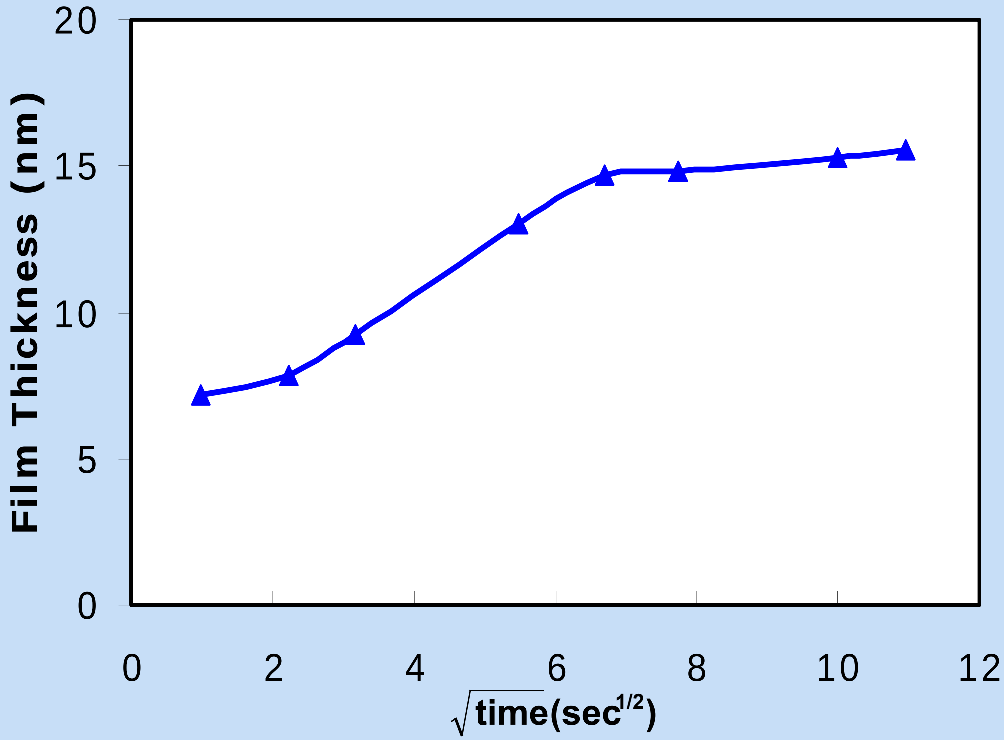




- The decrease in Rs is related to the growth of the Ni_2Si phase

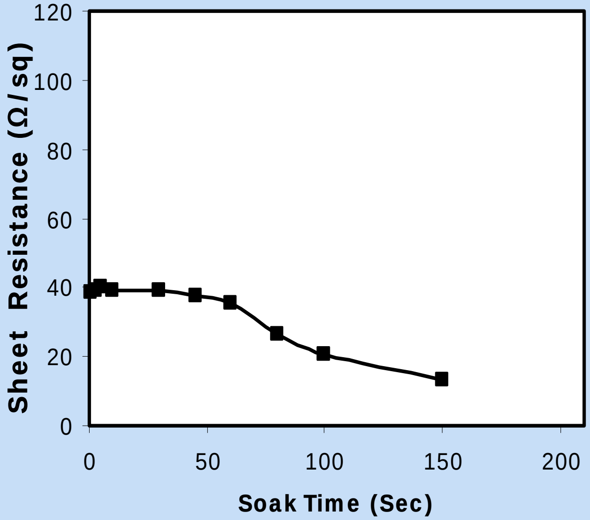
Film Thickness: Ni_2Si Growth

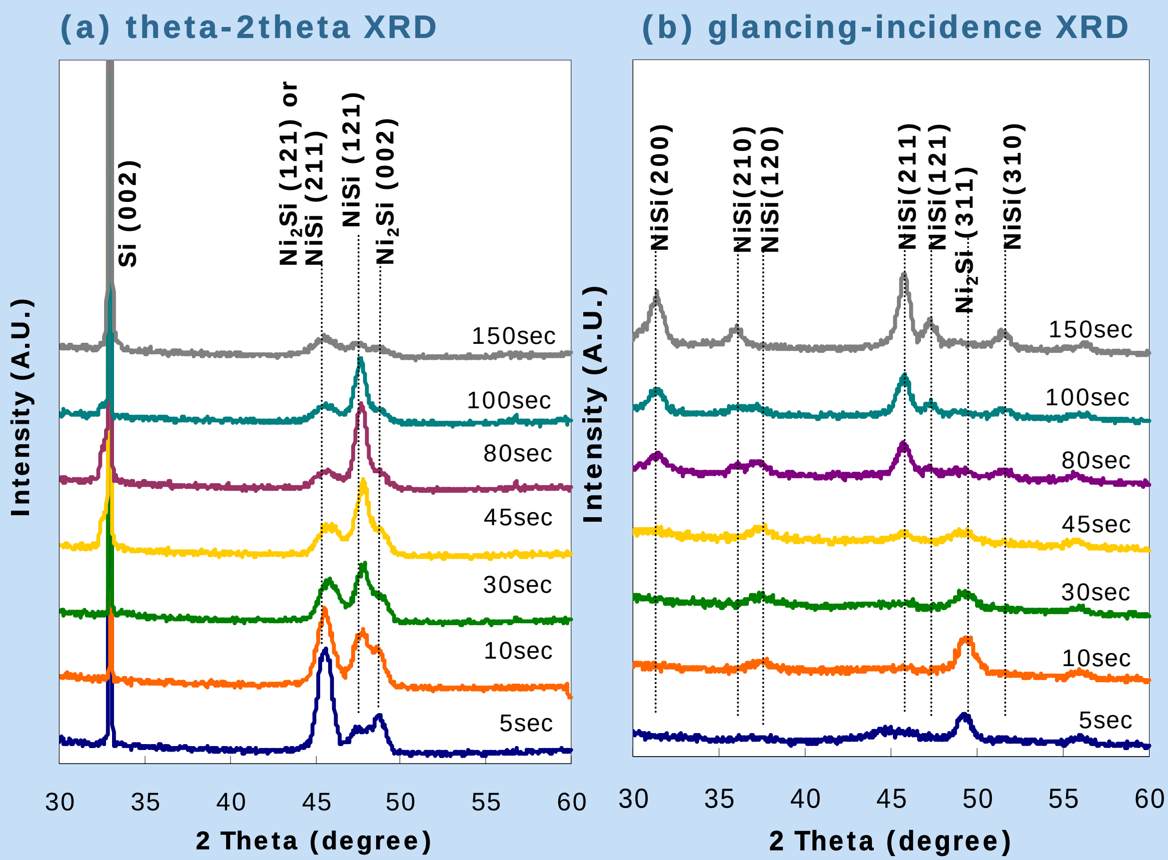




- XRR was employed to measure the thickness of Ni_2Si
- The Ni_2Si thickness is linear with the square root of the anneal time, which suggests that the growth is controlled by the Ni diffusion

XRD Spectra from 300°C Samples





- The Ni_2Si-NiSi transformation is observed at 300°C with increasing the anneal time
- The (121) NiSi peaks decrease, in accordance with the decrease in Rs
- NiSi formation can be confirmed using GI-XRD

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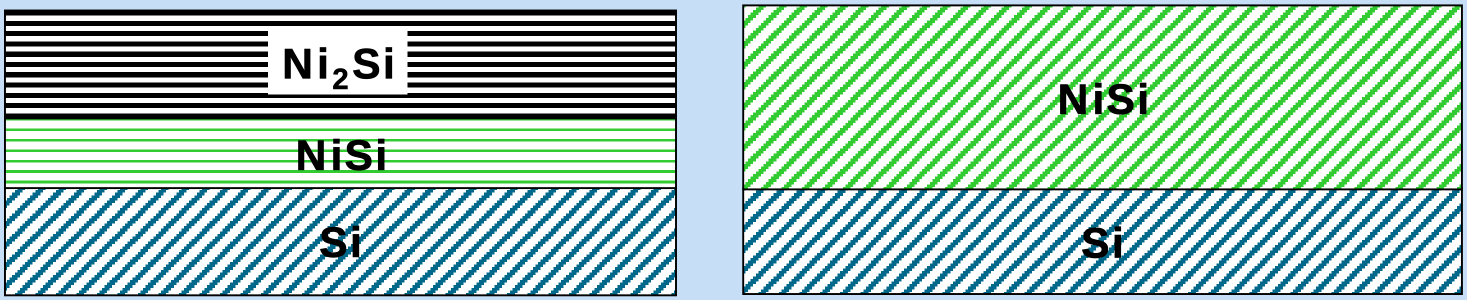
Preferred Texture During the Ni_2Si-NiSi Transformation



- The sequence includes the initial formation of NiSi and then changes in the alignment of NiSi (121) planes with respect to the Si (001) planes
- Small mismatch between the NiSi (121) and Si (110)
- The preferred texture of NiSi is related with the low resistance phase

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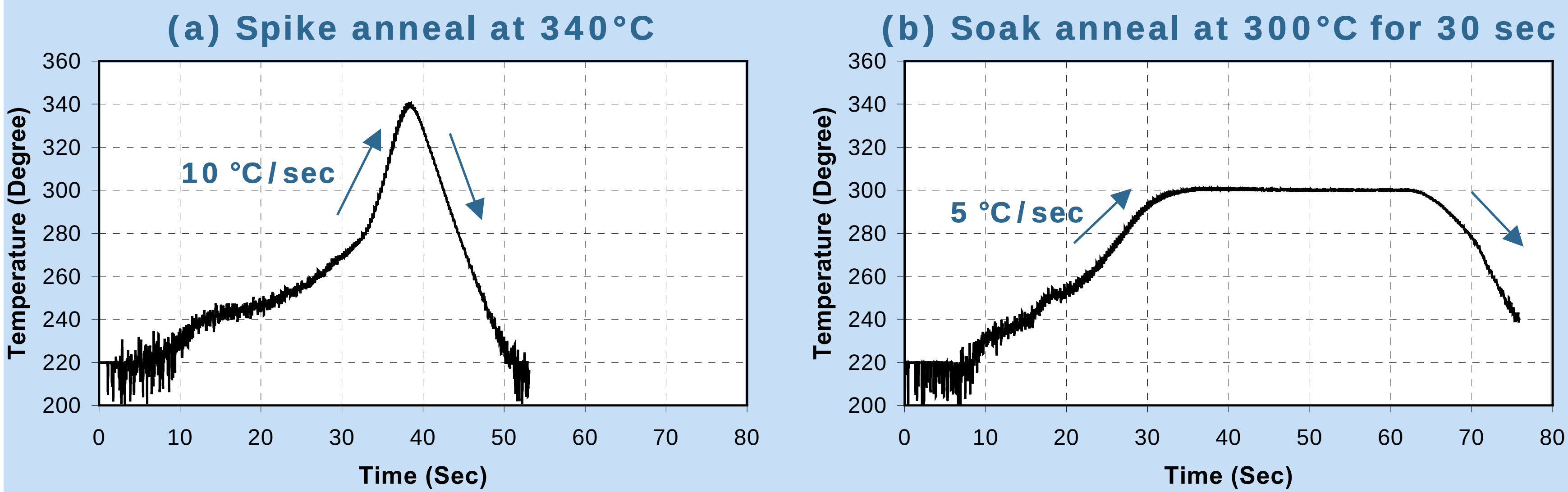
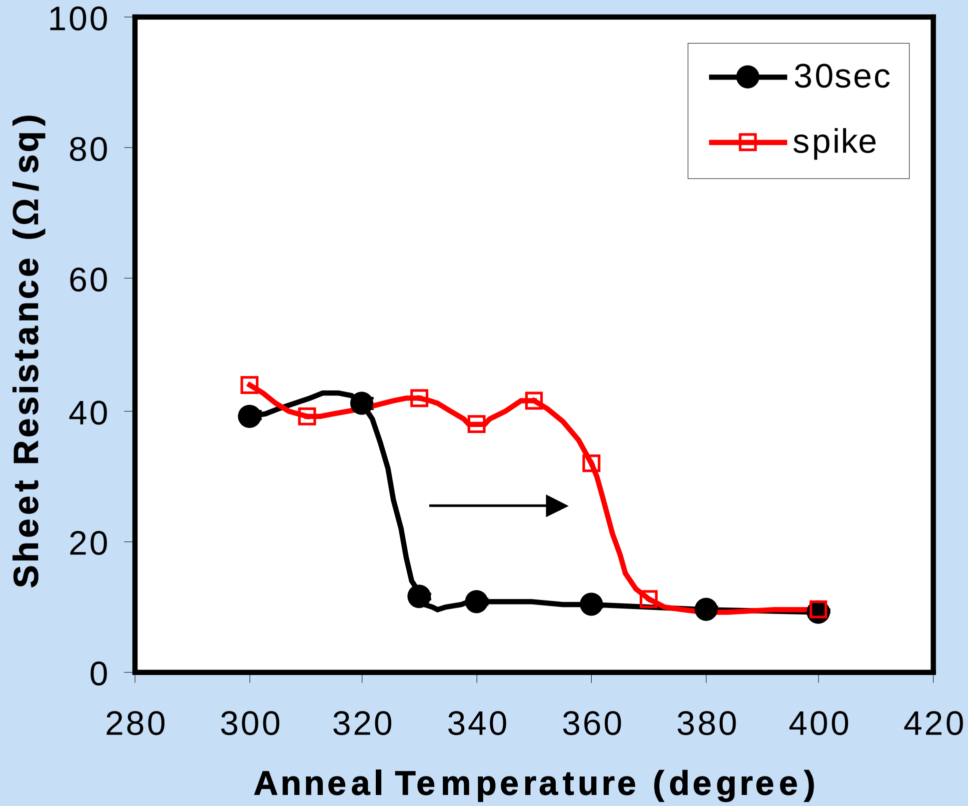
Spike RTP: Temperature-time Profile



- Spike RTP anneals use faster rampings to the peak temperature with negligible soak
- The thermal cycle time is reduced in the spike anneals

Rs After Spike RTPs



- Rs drops between 350 and 370°C, which is associated with the formation of the low resistance NiSi phase
- Compared with the soak RTP for 30 sec, the onset of the Rs decrease shifted to higher temperatures by ~40°C

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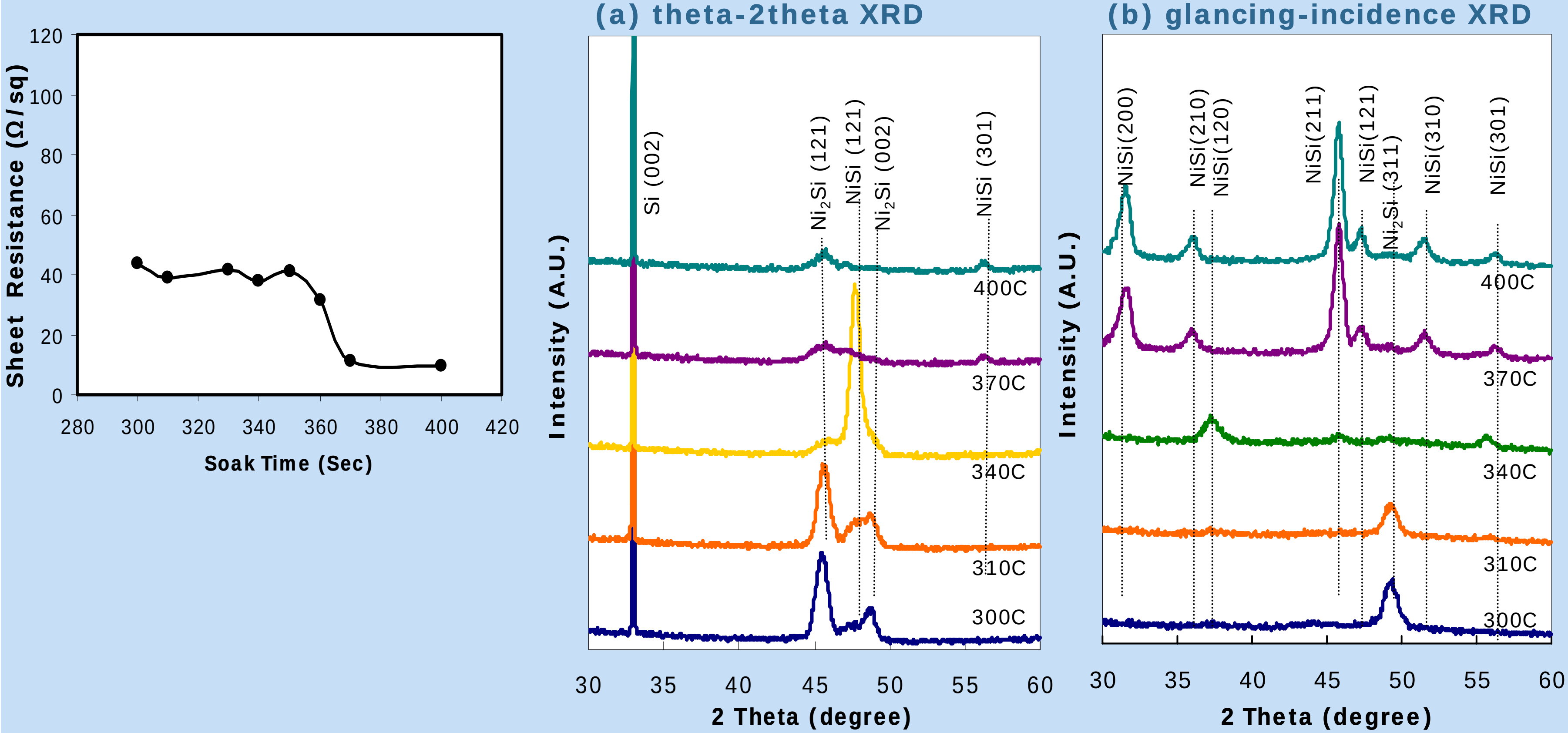
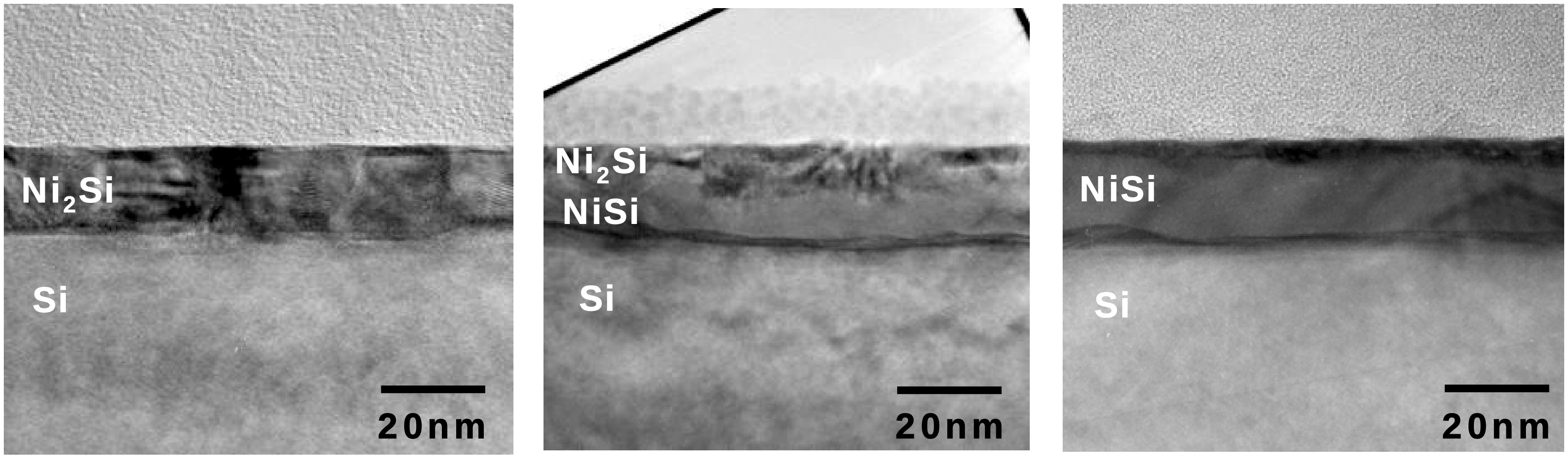
XRD for the Spike Samples



- The Ni_2Si-NiSi transformation is observed from the spike samples with raising the peak temperature
- The spike anneals result in the same sequence in the Ni_2Si-NiSi transformation as the soak anneals at 300 °C

TEM Images from the Series of Spike Samples

(a) T=310 °C (b) T=340 °C (c) T=370 °C



- Spike anneal at 310 °C → Mostly Ni_2Si
- Spike anneal at 340 °C → Ni_2Si and NiSi
- Spike anneal at 370 °C → Mostly NiSi with the thin Ni_2Si top layer
- This series of TEM pictures shows the progressive transformation from Ni_2Si to NiSi with increasing the peak temperature

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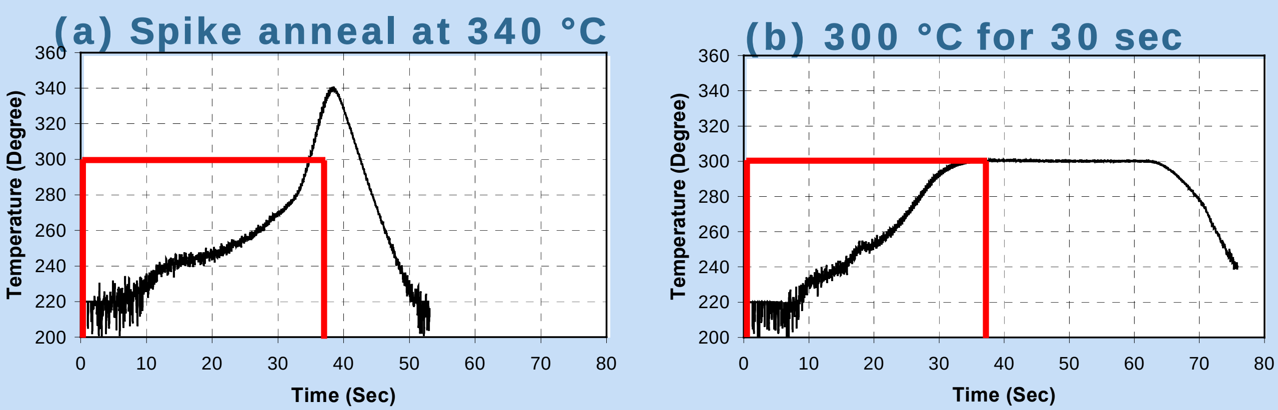
Effective Time Approach

$$t_{eff} = \int dt' \exp[E_a(1/kT_{ref} - 1/kT(t'))]$$

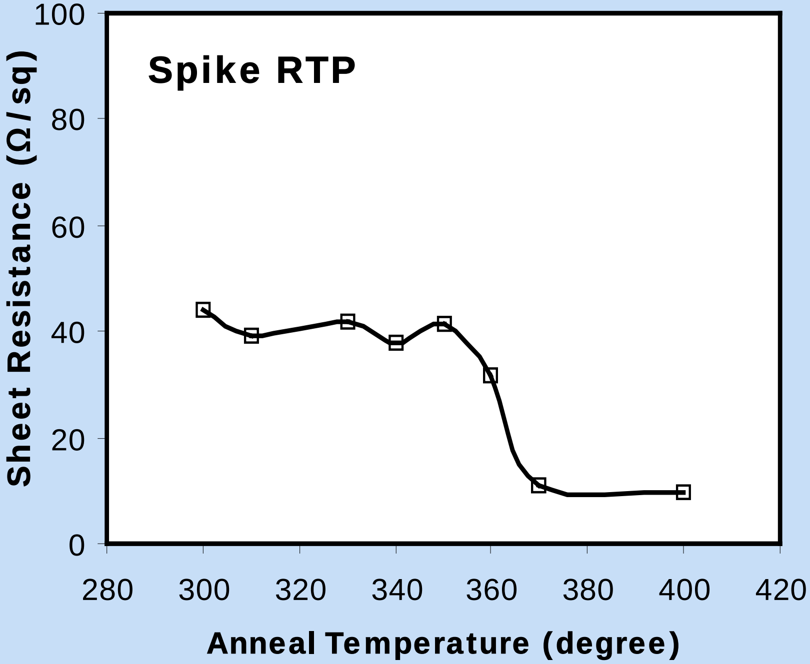
Source: A. T. Fiory and K. K. Bourdelle, Appl. Phys. Lett. 74, 2658 (1999)

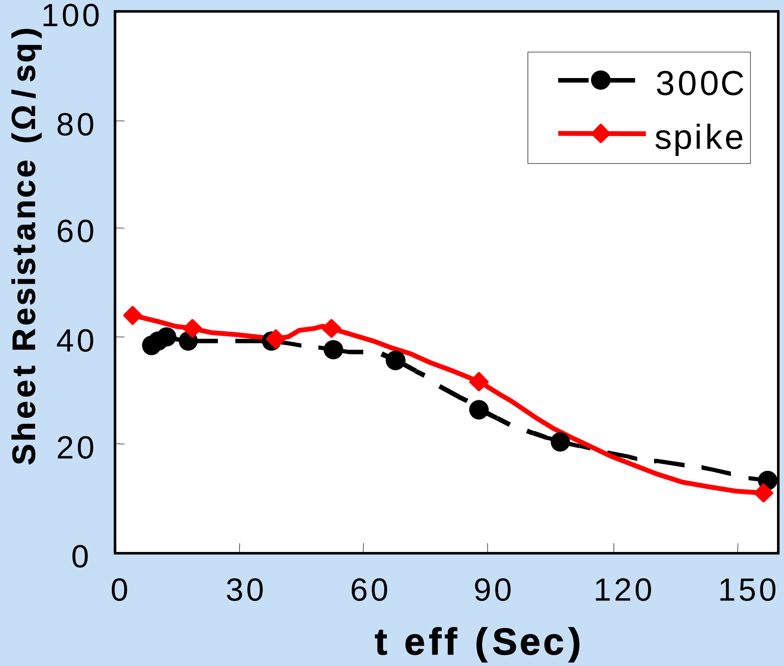
- This provides with a method to convert an anneal with T(t) to an equivalent anneal at the constant temperature, T_{ref}.
- To convert, we choose T_{ref}=300 °C and Ea=1.8 eV for the silicide process



- These two anneals show similar effective anneal time for the silicide reaction

Spike RTP: Equivalent Anneal at 300°C





- Through the effective time calculation, the spike RTP anneals are compared with the soak RTP at 300 °C
- For the two RTP schemes, Rs trends are identical with the effective time
- The effective time is useful to compare anneals with different rampings and temperatures

Effective Time, t_{eff} for Ni diffusion

RTP Temperature	Dwell Time	t_{eff} for silicide reaction (Ea=1.8eV)	t_{eff} for Ni diffusion (Ea=0.76eV)
270	200	~40	109
300	30	~40	51
340	0 (spike)	~40	28

- Three anneals are equivalent in terms of the silicide reaction
- The Ni diffusion is a source of silicide related defects and junction leakage currents
- The Ni diffusion can be minimized by using the spike RTP

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Summary and Conclusions

- Low temperature reaction between Ni and Si has been investigated using soak and spike RTPs
- Ni_2Si growth is observed at 270 °C with varying the anneal time
- Ni_2Si -NiSi transformation occurs at 300 °C, and its sequence includes the initial formation of NiSi and the change in the alignment with respect to Si substrates
- Spike RTP follows the parallel trend with soak RTP in terms of the Ni_2Si-NiSi transformation
- With the consideration of lower activation energy for the Ni diffusion, the spike RTP scheme can be effective in preventing the defect formation and the Ni diffusion into the junctions

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