A New Technology for Depth Profiling of Electrical Properties at Atomic-Level Resolution

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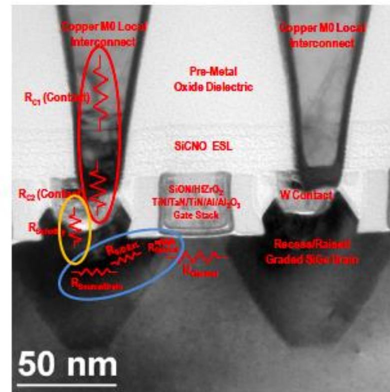
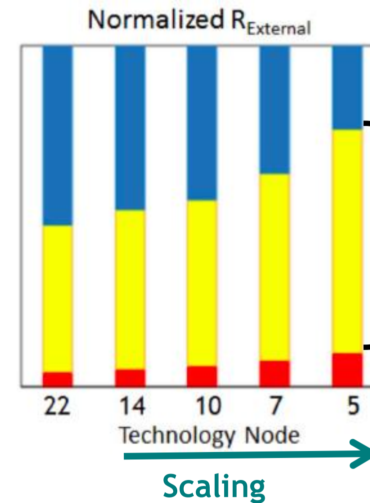
Introduction

- Simply scaling does not provide the benefits that it once did; we have to look at new materials technology & scaling
- Current and future technologies (SOI and FinFETs) rely on:
  - Materials engineering in channel, source and drain regions
  - High mobility materials- Si:Ge, Ge, and III-V
  - More control of dopant activation and Rs at S/D contact regions
  - Epi material control and understanding
- Tools with capability to adequately profile device-critical thin-film *electrical* parameters did not exist…until now
- ALP has developed a technology (ALPro^{TM}) based on Differential Hall Effect Microscopy (DHEM) with such capability

Need

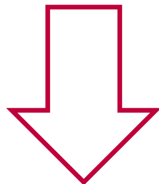
For IC manufacturers enhancing the performance of the MOS transistor is **critical** for continued market growth





Contact interface resistance dominates device performance

Ref: 2016-IEDM tutorial



- Device scaling
- New materials (Ge, III-V compounds)

$\rho_c \propto$ **exp(C/N$^{1/2}$)** ; N is carrier density near contact/SC interface → depth profile of N needs to be measured at atomic level resolution right near the surface

Processes (deposition, doping, annealing, etc.) are being developed to yield higher mobility layers → Process/performance correlations need to be established

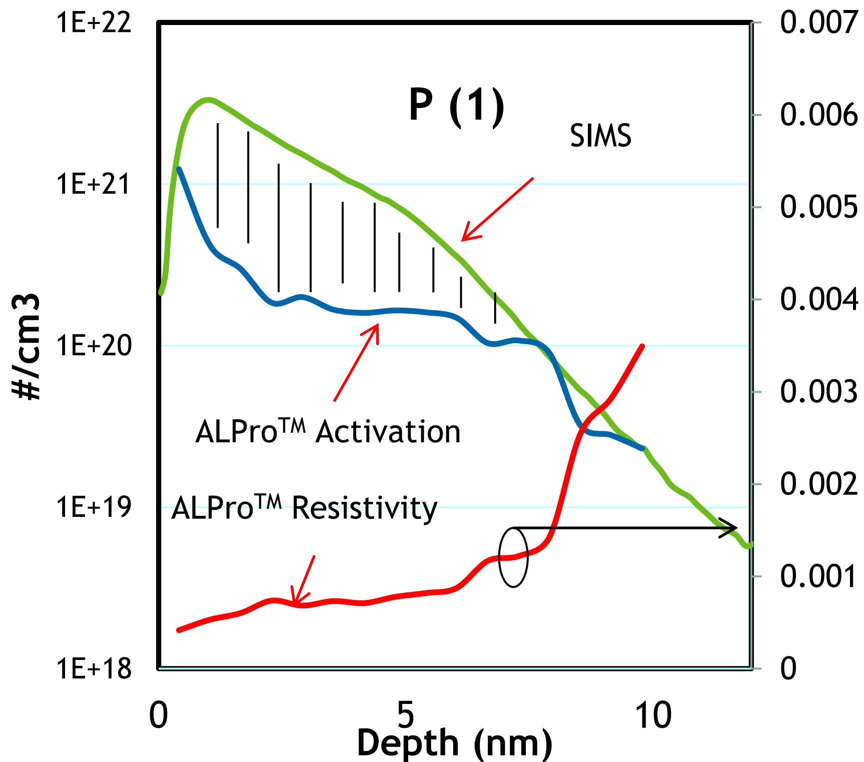
The technique: Differential Hall Effect Microscopy (DHEM)

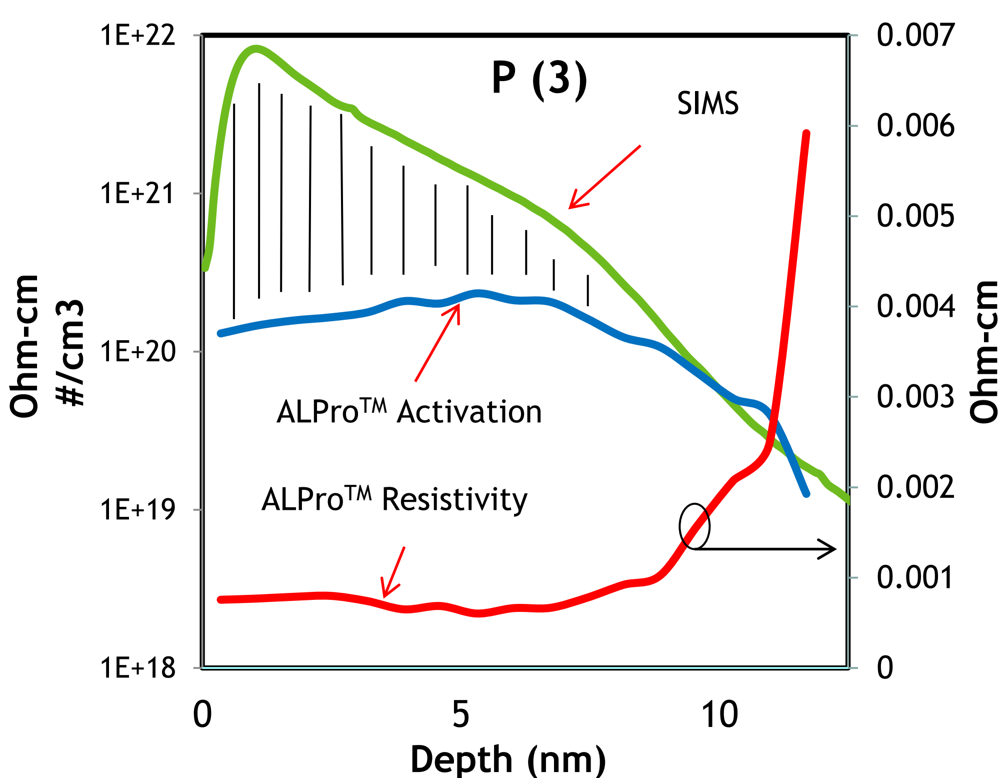
- DHE has long been used in laboratories employing manual experimental setups. It typically has very long measurement times (many hours, even days) and yields typical depth resolution of >1nm.
- DHEM is an implementation of Differential Hall Effect (DHE) method for fully automated electrical depth profiling of thin films at sub-nm depth resolution.

<10nm Ultra shallow P in Si for S/D

Goal: *Measure details of dopant activation in the top 10nm of P-doped epi-Si films processed under different conditions.*

Dose P(3) = 3x Dose P(1) + millisecond anneal (MSA) conditions





Result: *Different surface dopant activation was detected for samples processed under two different conditions. Higher dose dopant yielded lower carrier concentration.*

Si doped GaAs dopant activation and mobility

<u>Goal:</u> *Evaluate dopant activation and mobility through Si:GaAs epi on Si substrate*

GaAs

SIMS (Si)

ALPro™ Carriers

ALPro™ Mobility

#/cm3

1E+22
1E+21
1E+20
1E+19
1E+18
1E+17
1E+16

cm2/V-s

5000
4000
3000
2000
1000
0

0 200 400 600 800 1000 1200 1400 1600

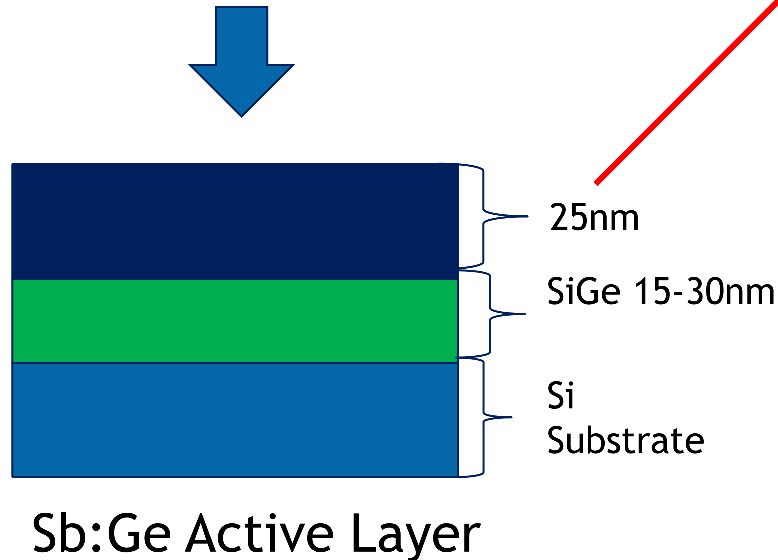
Depth(A)

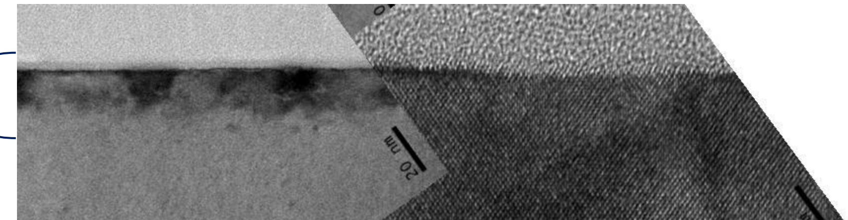
<u>Result:</u> *ALPro successfully showed the variation in dopant activation and mobility through the GaAs layer.*

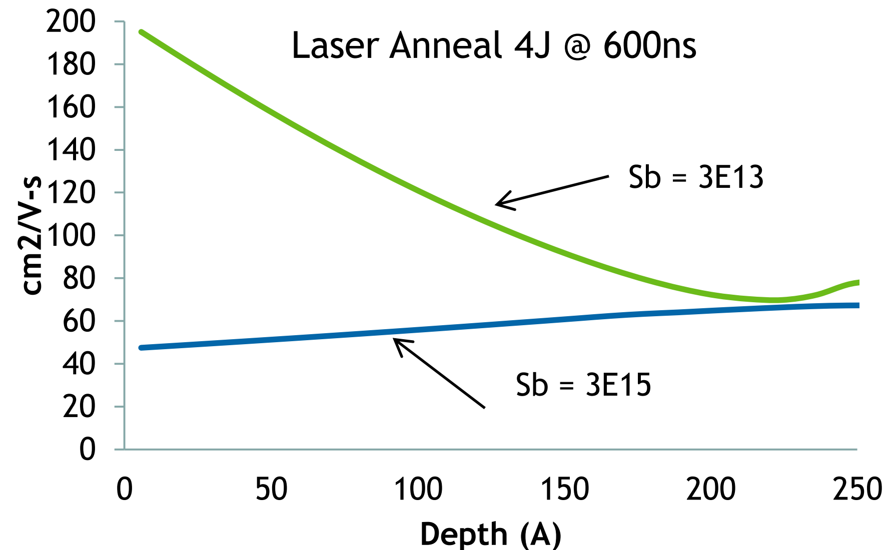
SbGe for high-mobility channels

Goal: *Show interrelation between Sb concentration and mobility in Ge.*

1st Sb 3E13 or 3E15 (3keV),
2nd Ge 5E16 (3keV),
3rd Laser Anneal







Result: *ALPro provided, in profile form, the mobility variation through the high Ge concentration film. Lower Sb dose resulted in higher mobility near the surface.*

ALPro™50 System

- Can make measurements on sample coupons <50mm in size.
- Sample alignment is manual, measurement is fully automated.
- Yields depth profiles of mobility, resistivity, carrier concentration at sub-nm resolutions (0.3 nm for Si).
- Processes have been developed for Si, Ge, Si-Ge alloys. Other semiconductor recipes are also available.
- Measurement recipes for 3D structures are in development

ALPro™50 System in operation

For a short video of the ALPro-50 system in operation please visit:

www.alpinc.net

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