

High Precision Fe Measurement in Si With Whole Wafer Mapping For Contamination Control in Ultra-Pure IC Fablines



For correspondence: mwilson@semilabsdi.com

Semilab SDI, 10770 N. 46th St., Ste. E700, Tampa, FL 33617, USA

M. Wilson¹, A. Savtchouk¹, B. Schraye¹, C. Almeida¹ and J. Lagowski¹

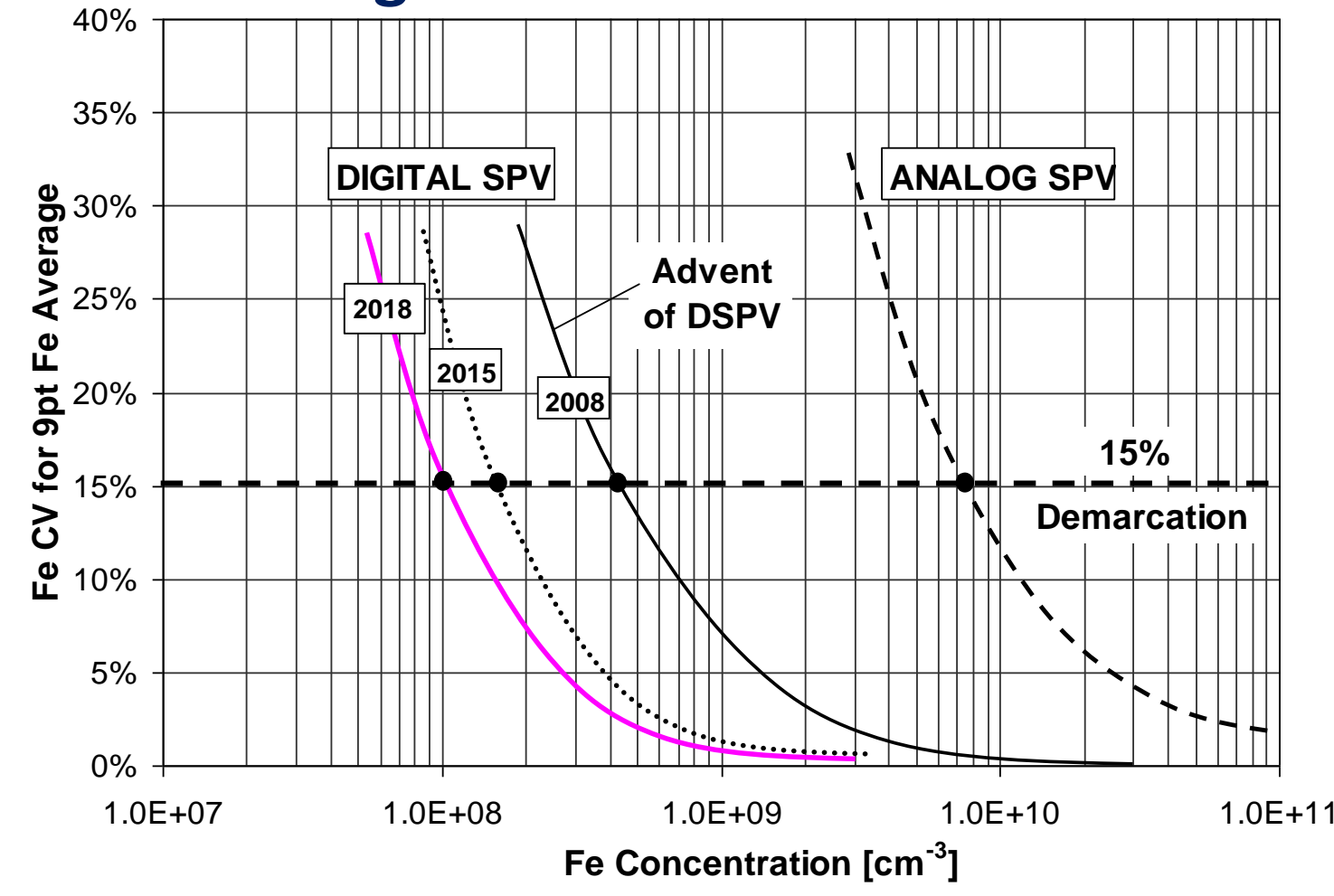
¹Semilab SDI, Tampa, FL, USA



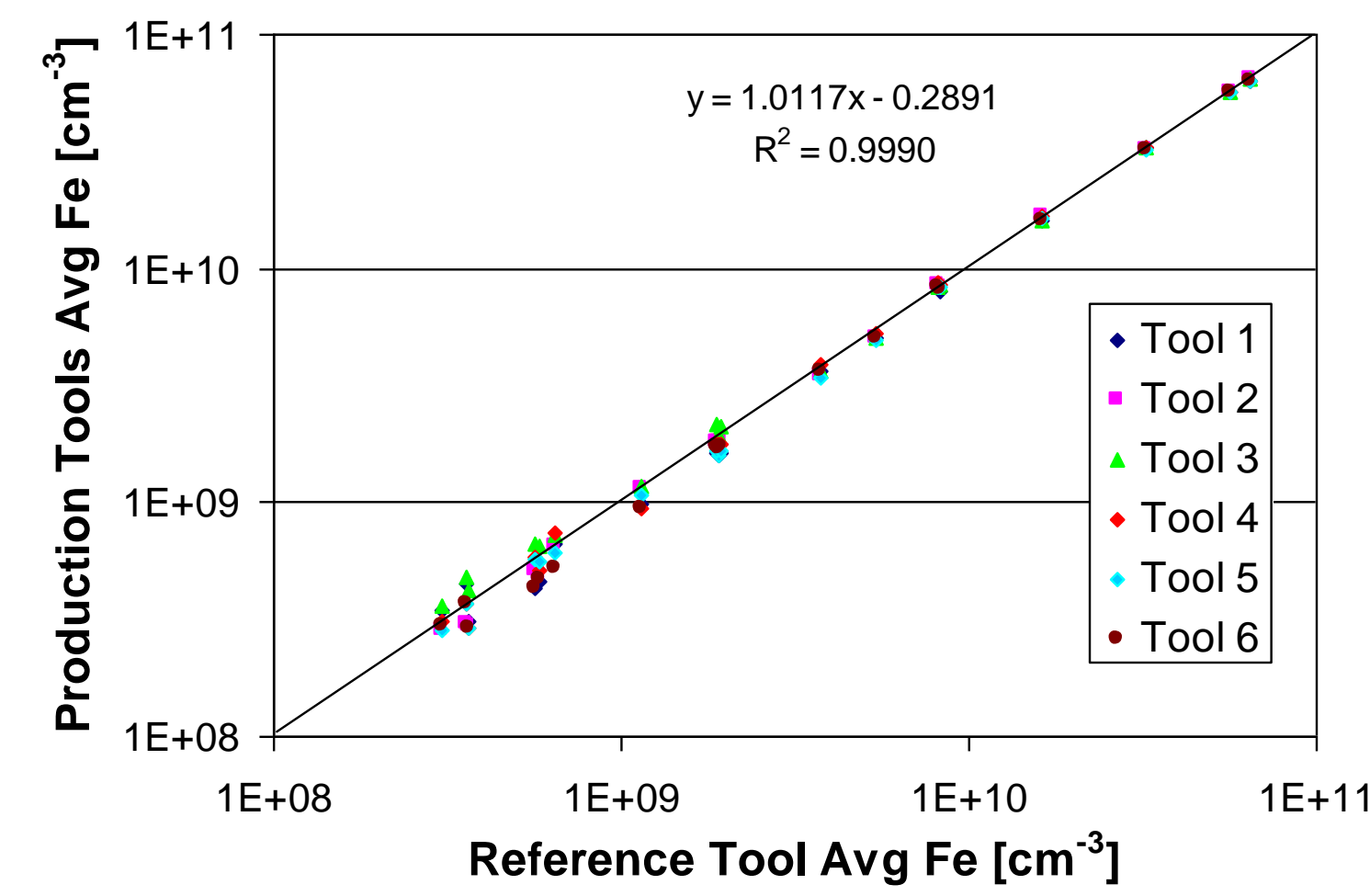
Introduction

- The Surface Photovoltage (SPV) minority carrier diffusion length method [1,2] is the most sensitive and widely used technique for monitoring heavy metal contamination in silicon wafers, starting from crystal growth through various IC processing steps.
- Among fast diffusing transition metals detrimental for device performance and IC yield, Fe has been receiving by far the largest attention. Relentless IC fabline purity refinement, exhibited by a Fe contamination decrease of about 10 times per decade, has been matched by progress in SPV and development of a new digital SPV, DSPV, for Fe detection in the 10⁸ cm⁻³ range [2]. DSPV may be the unique practical answer for production environment wafer monitoring for such a low Fe contamination range.
- In this work we discuss further developments in surface photovoltage (SPV) measurement of iron contamination in silicon with a goal to extend whole wafer mapping to ultra-low contamination levels. Sensitivity in the 10⁷ cm⁻³ range has become achievable in the latest generation SPV metrology for localized site measurements under ideal conditions [2]. This sensitivity range, unattainable in any other real-time feedback technique, matches the contamination limit projected for new IC fablines by the year 2020.

Progress in DSPV Fe Precision

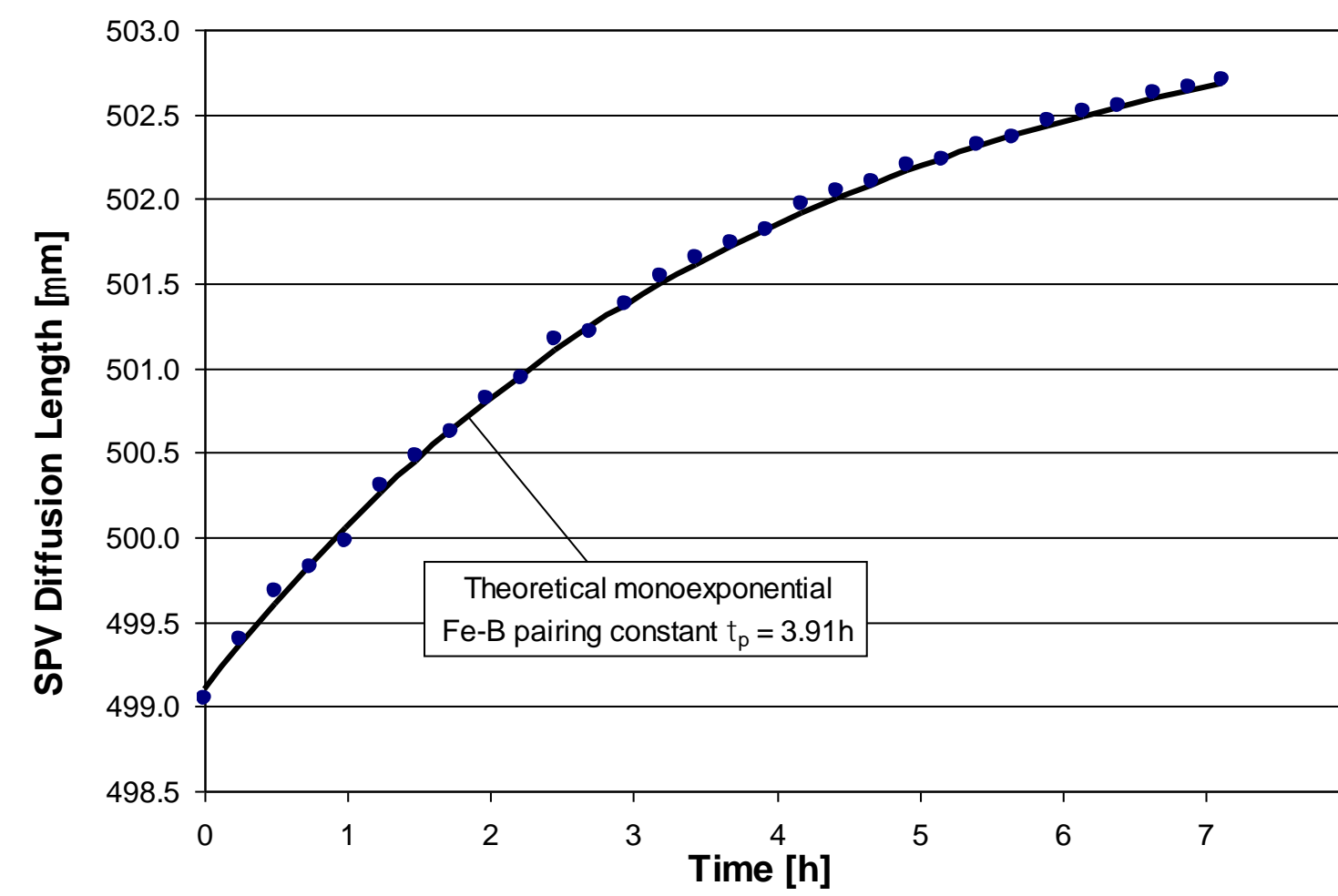


DSPV Fe Tool to Tool Matching



- Corresponding progress in Fe wafer mapping is of practical significance. The SPV mapping technique is used for evaluation of contamination in as-grown and processed wafers in IC fablines. The maps reveal specific contamination patterns invaluable for identifying contamination sources from tools and processes.
- The recent progress in SPV metrology includes three key elements: (1) The accuracy and repeatability of the SPV determination of the minority carrier diffusion length L. This is critical for Fe measurement based on L values before and after iron activation. (2) Improved Fe activation: New whole wafer digital optical activation station with IR LED arrays replaces the previous generation of flash activation. Enhanced intensity control, uniformity, and improved SPV signal stability after activation enables resolving smaller changes of L corresponding to ultra-low Fe levels. (3) Quick in-situ identification of metals. No other real-time feedback technique can measure Fe in the 10⁷ cm⁻³ range, therefore, confirmation that it is indeed iron that is measured by SPV is of fundamental importance.

Unique Identification of Fe with the Diffusion Length Transient Method

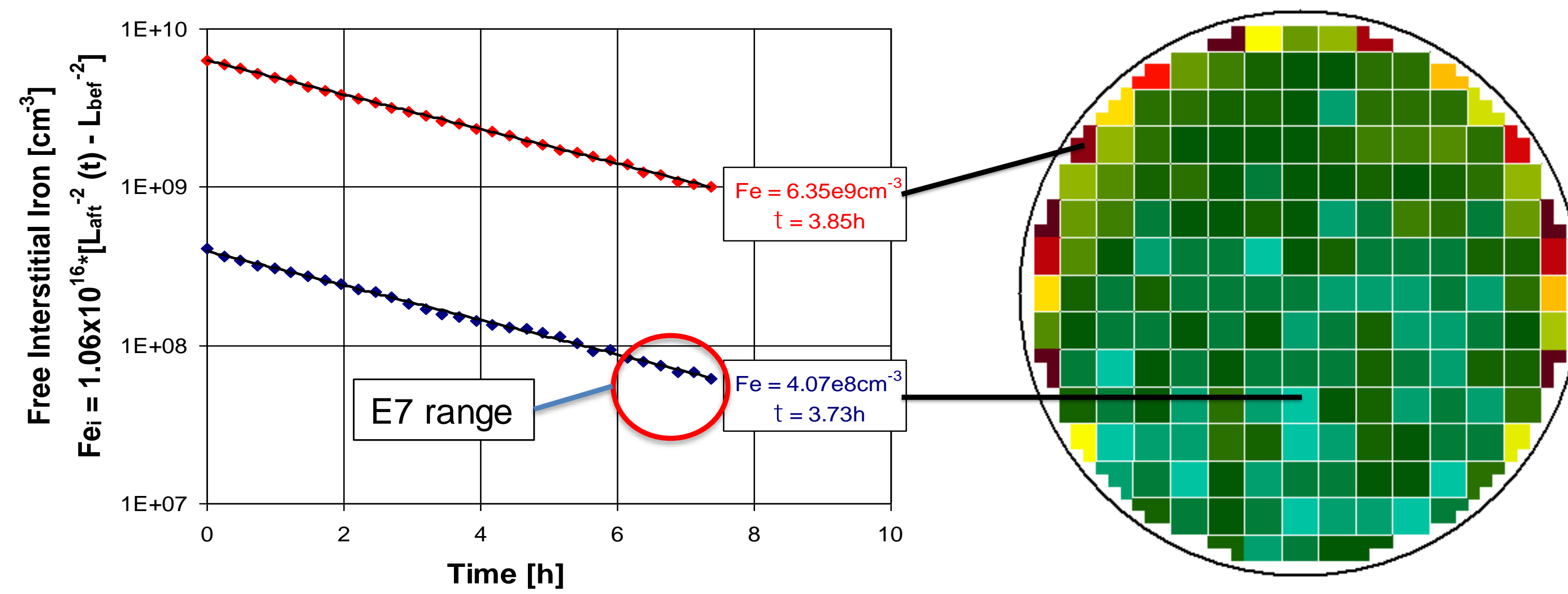


$$\tau = \frac{\varepsilon \varepsilon_0 k T}{q^2 D N_B} \quad \begin{matrix} D - \text{diffusivity (Fe)} \\ N_B - \text{boron concentration} \end{matrix}$$

for Fe-B after J. Tan et al., (2011)

$$\tau = \frac{5.7 \times 10^5 T}{N_B} \exp\left(\frac{0.66}{kT}\right)$$

High precision Digital SPV measures transients even in E7 cm⁻³ iron range

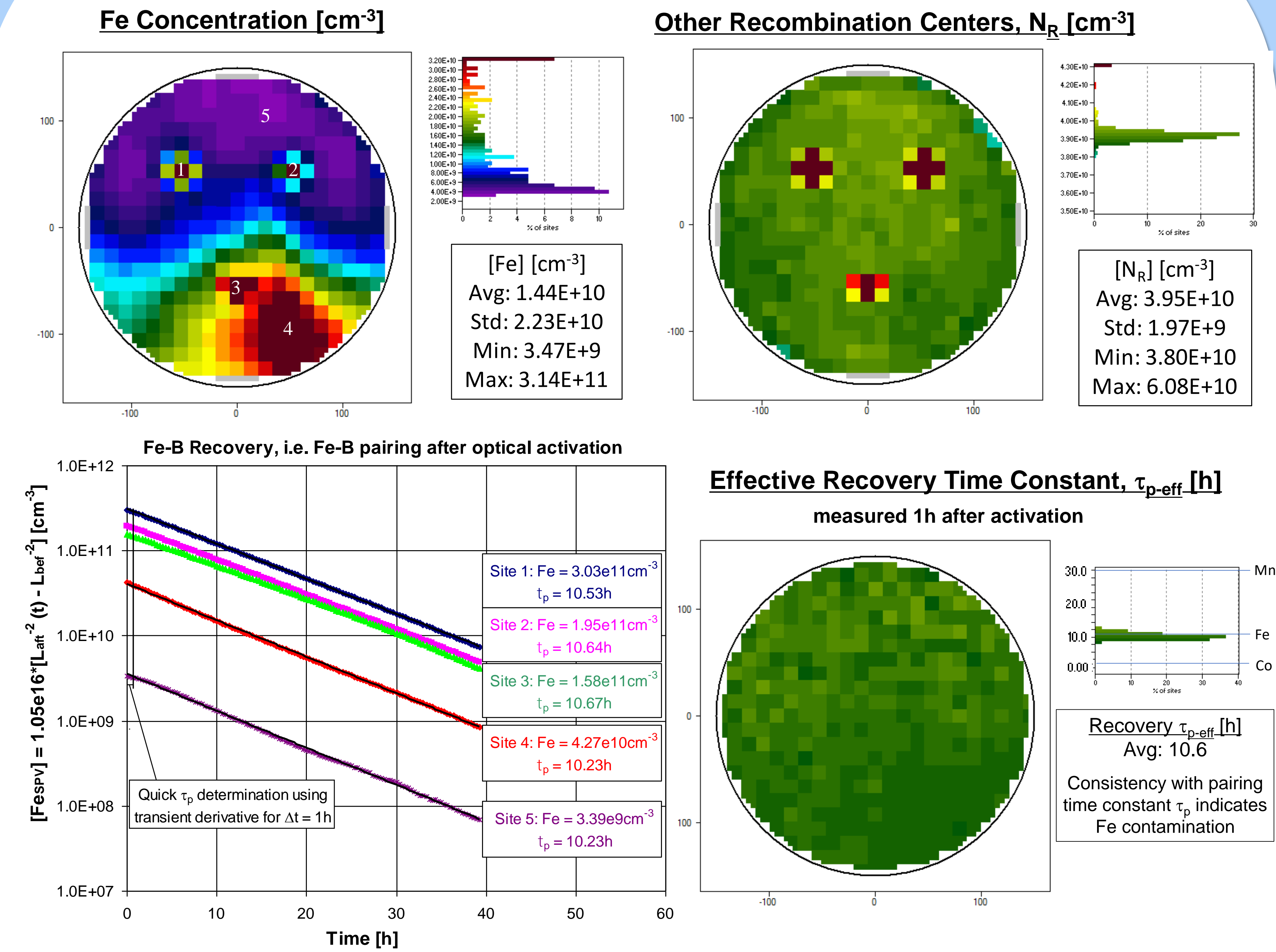


- In p-type boron doped Si at room temperature Fe is paired with boron in equilibrium. Optical activation dissociates Fe-B pairs producing free iron interstitials (Fe_i) that are stronger recombination centers, thereby decreasing the diffusion length [3].
- After activation, Fe_i diffuses and associates with B. The Fe_i concentration decreases exponentially with time and a corresponding pairing time constant (τ_p) uniquely identifies Fe [4].
- Other metals that form metastable pairs with boron have a distinctly different τ_p , allowing them to be differentiated from Fe. Room temperature τ_p : Co-B (minutes), Fe-B (hours), Mn-B (days) and Cr-B (weeks).

REFERENCES

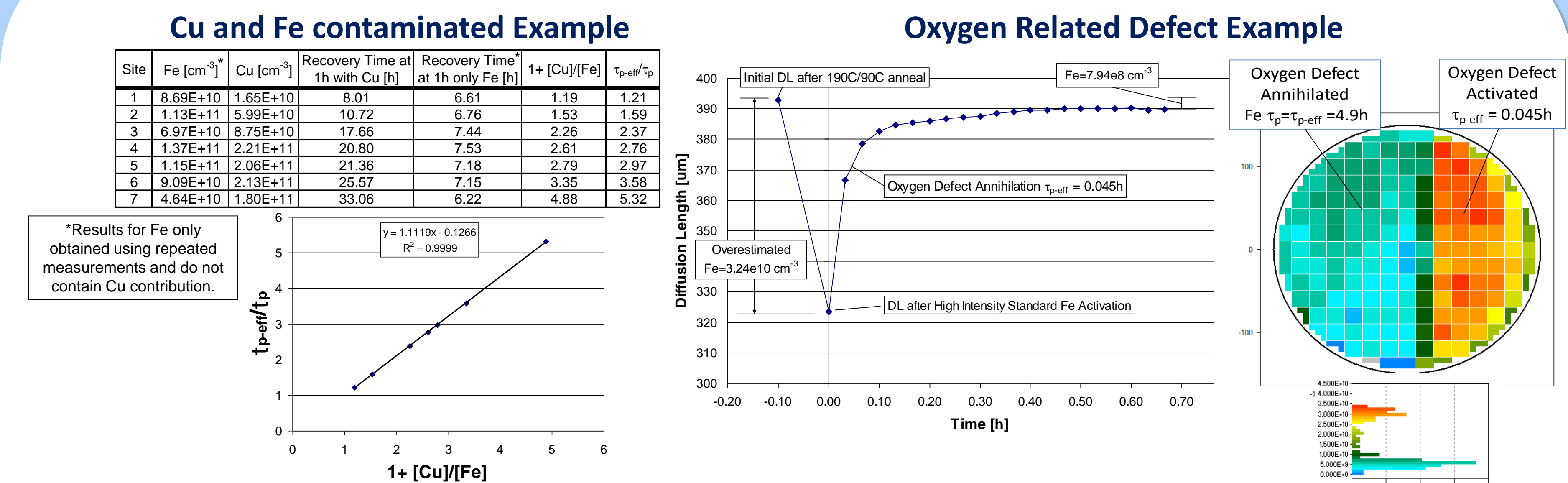
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Full Wafer Mapping of Pairing Time Constant



- Traditional measurements of τ_p require transient monitoring lasting many hours or even days which is not practical in an IC fab.
- Recent improvements facilitated by increased SPV precision enabled the ability to resolve very small changes of diffusion length in short time intervals. The corresponding new quick Fe identification test uses differential measurement of the initial diffusion length transient just after activation.
- Corresponding measurement at time, t, after activation is the effective recovery time constant, $\tau_{p\text{-eff}}$. When iron is the only activated center, $\tau_{p\text{-eff}}$ equals the actual pairing time τ_p . In this work we demonstrate for the first time Fe measurements that include full wafer mapping of $\tau_{p\text{-eff}}$.

Influence of Other Optically Activated Centers on Recovery Time



- In samples contaminated with both Fe and Cu, the unrecoverable Cu contribution to diffusion length results in the overestimation of the effective recovery time ($\tau_{p\text{-eff}}$) compared to the ideal τ_p for Fe-B. The overestimation of τ_p scales with Cu/Fe ratio.
- The presence of oxygen related traps generated during high intensity Fe activation result in a large decrease of DL and the underestimation of Fe τ_p . These oxygen related defects are quickly annihilated with subsequent low intensity illumination [5] enabling reliable Fe measurement as demonstrated by $\tau_{p\text{-eff}}$ that equals τ_p on the illuminated part of the wafer shown above.

CONCLUSIONS

- Continuing improvements in the precision of digital SPV monitoring of bulk Fe contamination to levels below 1x10⁸cm⁻³, has allowed the technique to keep pace with the relentless push for reduction of metallic contamination in IC fablines.
- The recent precision improvement in DSPV diffusion length transient measurement allows for identification of Fe contamination using a quick derivative method with testing times of minutes instead of hours or days as in previous approaches.
- We believe that in-situ $\tau_{p\text{-eff}}$ full wafer mapping, demonstrated for the first time, shall prove a powerful practical means for quick identification of Fe and quick evaluation of the role of other transition metals.