# Thin metal film 4H-SiC vertical Schottky photodiodes for UV Index monitoring

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# Outline



- Introduction
- Photodiode fabrication
- Morphological characterization
- Electro-optical characterization
- Conclusions

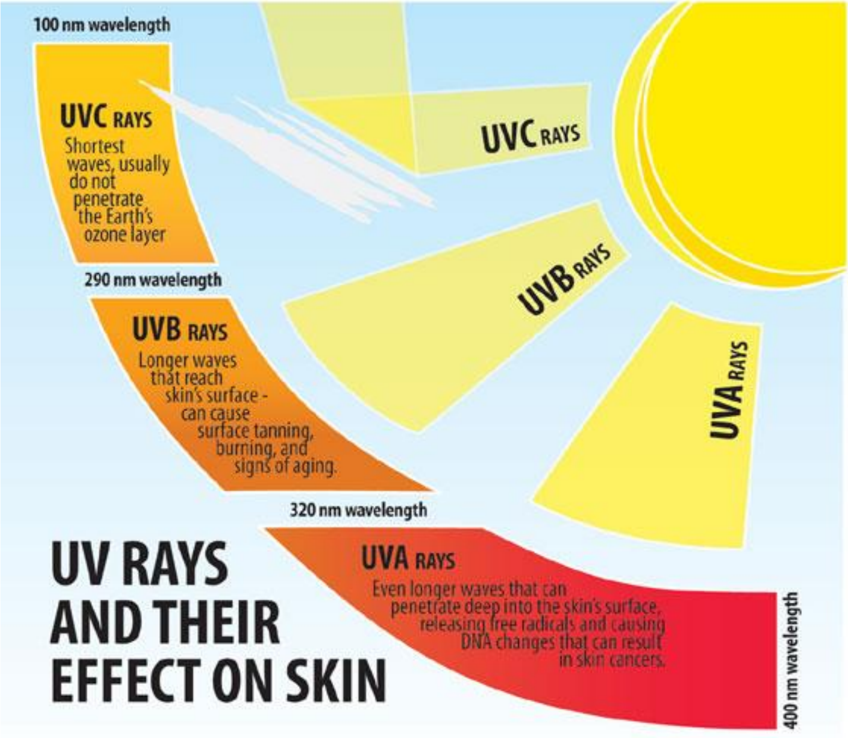
# Introduction

# The ultraviolet region



- The UV region covers the wavelength range 100 - 400 nm
- As sunlight passes through the atmosphere, all UV-C and about 90% of UV-B radiation are absorbed
- The UV radiation reaching the Earth's surface is composed of UV-A with a small UV-B component
- An excessive exposure to UV radiation may cause acute and chronic adverse health effects to skin and eye

| | |
|---|---|
| UV-A | 315 – 400 nm |
| UV-B | 280 – 315 nm |
| UV-C | 100 – 280 nm |



# The UV Index



- The UV Index (UVI) describes the degree of dangerousness of solar UV radiation at the Earth's surface

- It is defined as

$$UVI = K_{er} \int_{250\ nm}^{400\ nm} S_{er}(\lambda) E_\lambda d\lambda$$

- UVI is closely related to sun elevation, latitude, cloud cover, altitude, ozone and ground reflection

- For simplicity it is divided into different levels

| UV Index | Exposure level |
|---|---|
| 0 – 2 | Low |
| 3 – 5 | Moderate |
| 6 – 7 | High |
| 8 – 10 | Very high |
| 11+ | Extreme |

# The UV Index monitoring



- Photodetection in the UV region has drawn extensive attention owing to its application in biological and medical fields

- We propose a vertical 4H-SiC Schottky based detector operating in photovoltaic regime and coupled to an appropriate IC interface for the realization of an ultra-compact UVI sensor

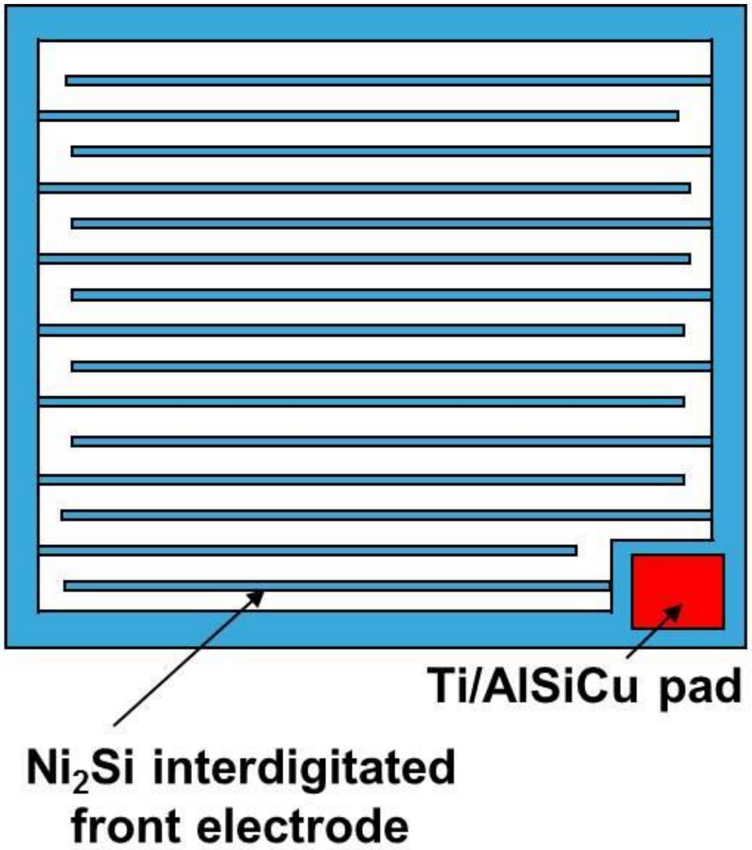
# Photodiode fabrication

# Previous generation - Interdigitated

- In the previous years a vertical 4H-SiC Schottky UV detector, based on the pinch-off surface effect, obtained by means of $Ni_2Si$ interdigitated contacts, has been developed

**Drawbacks**

- Difficulty to define with good reproducibility the width of the thin metal stripes
- Pinch-off affected by charge effects due to direct exposure of 4H-SiC surface

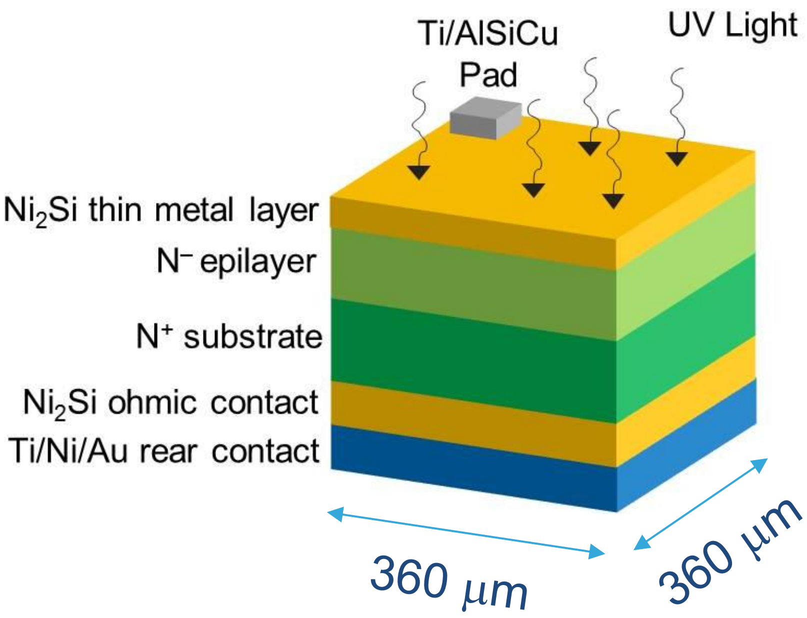



M. Mazzillo *et al.*, IEEE Phot. Tech. Lett., **Vol. 21**, No. 23, pp. 1782-1784 (2009)

# Adopted solution - Semitransparent metal



- An alternative solution, based on a Schottky contact realized through a continuous thin $Ni_2Si$ film has been proposed
- $Ni_2Si$ front layer has to be as thin as possible to guarantee a higher transmission in the UV range (10 nm Ni deposited; 20 nm silicide after RTP)
- Very low doping ($8 \times 10^{13}$ $cm^{-3}$) epilayer is required to have the maximum detection efficiency at 0 V
- A sensitive area of 0.36 x 0.36 $mm^2$ has been chosen



# Morphological characterization

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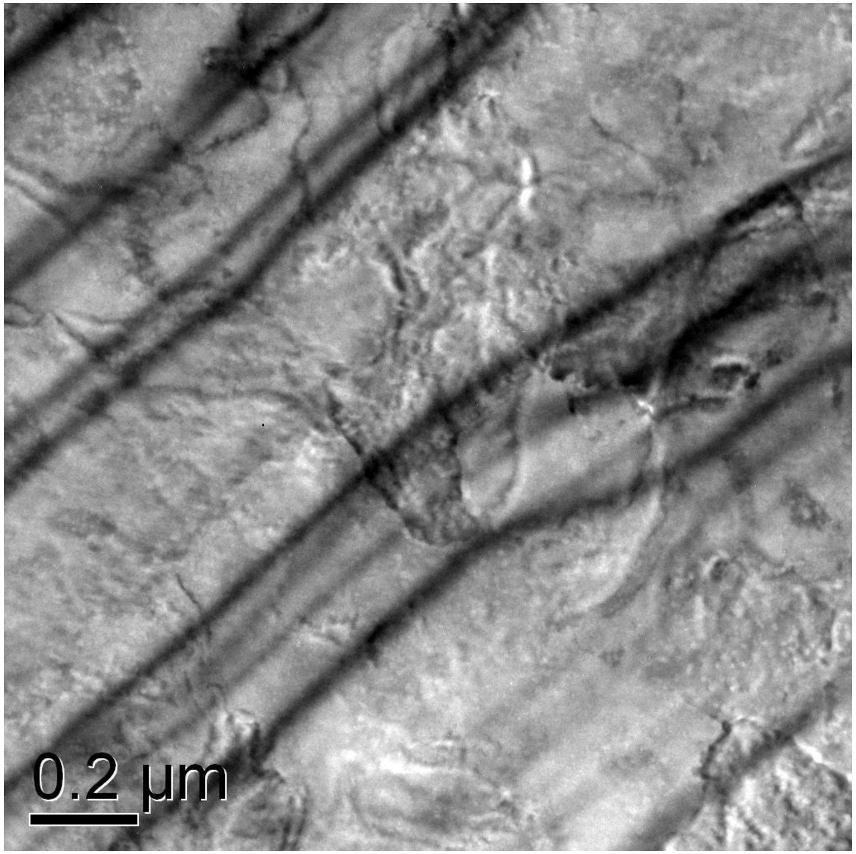
# Plan view TEM analyses



- First of all the continuity of $Ni_2Si$ film has been verified by means of plan view TEM analyses

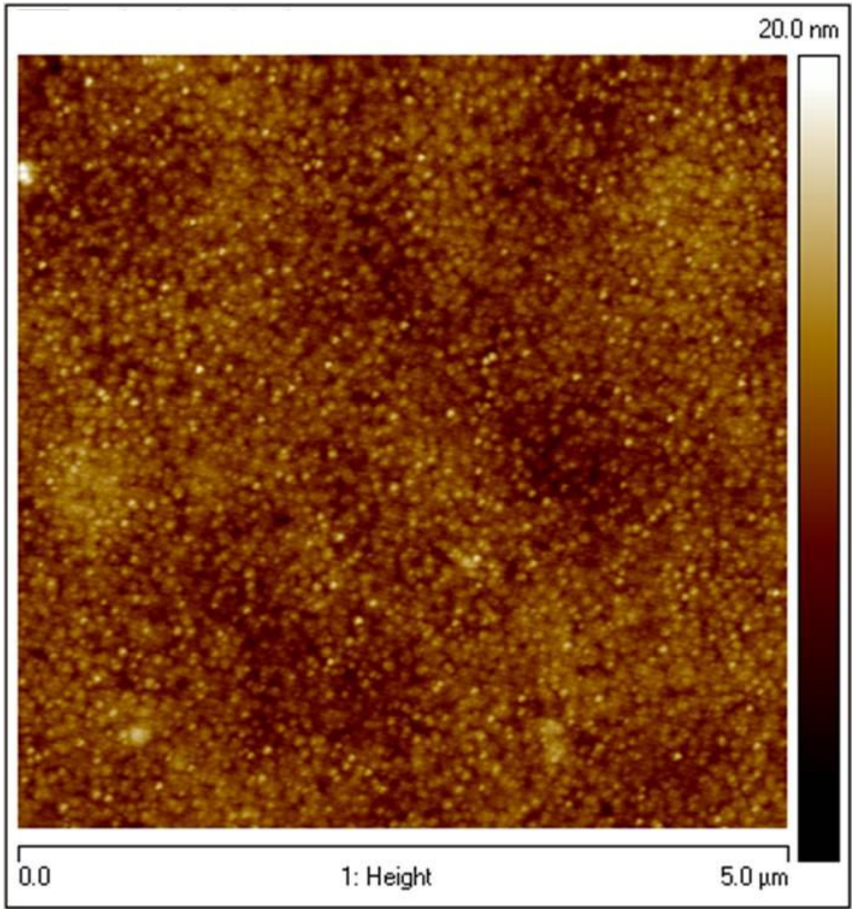
- The fringes visible in this micrograph are due to the sample preparative, that gives a radial gradient of sample thickness



# AFM analyses



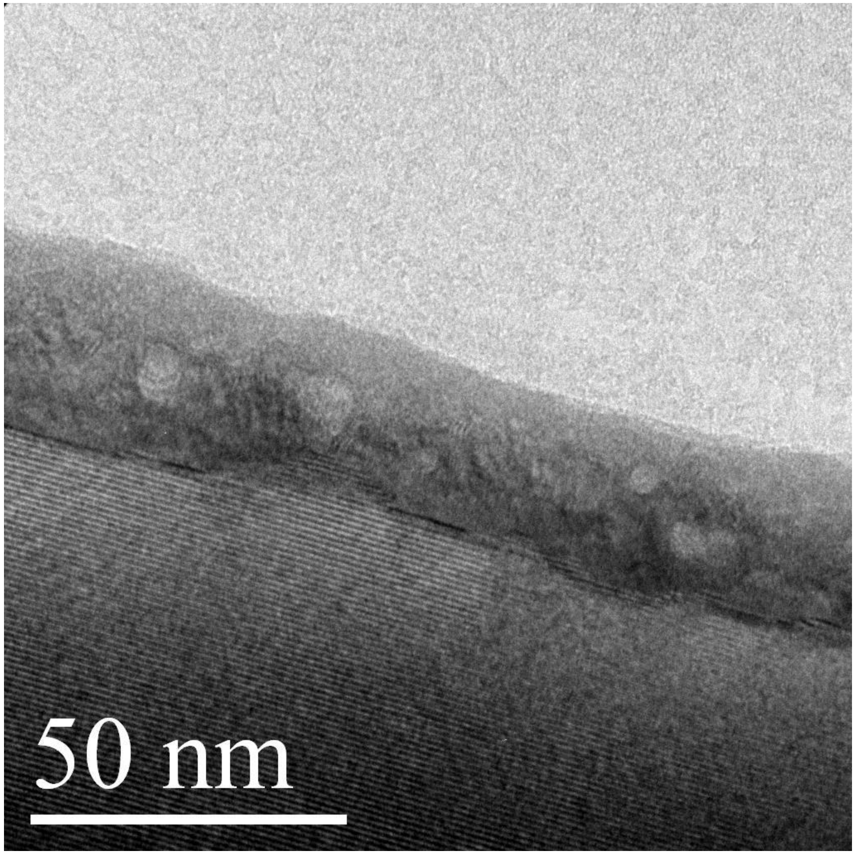
- The surface of $Ni_2Si$ film has also been investigated by means of AFM
- The film is uniform and exhibits low roughness. The value of RMS is 1.52 nm



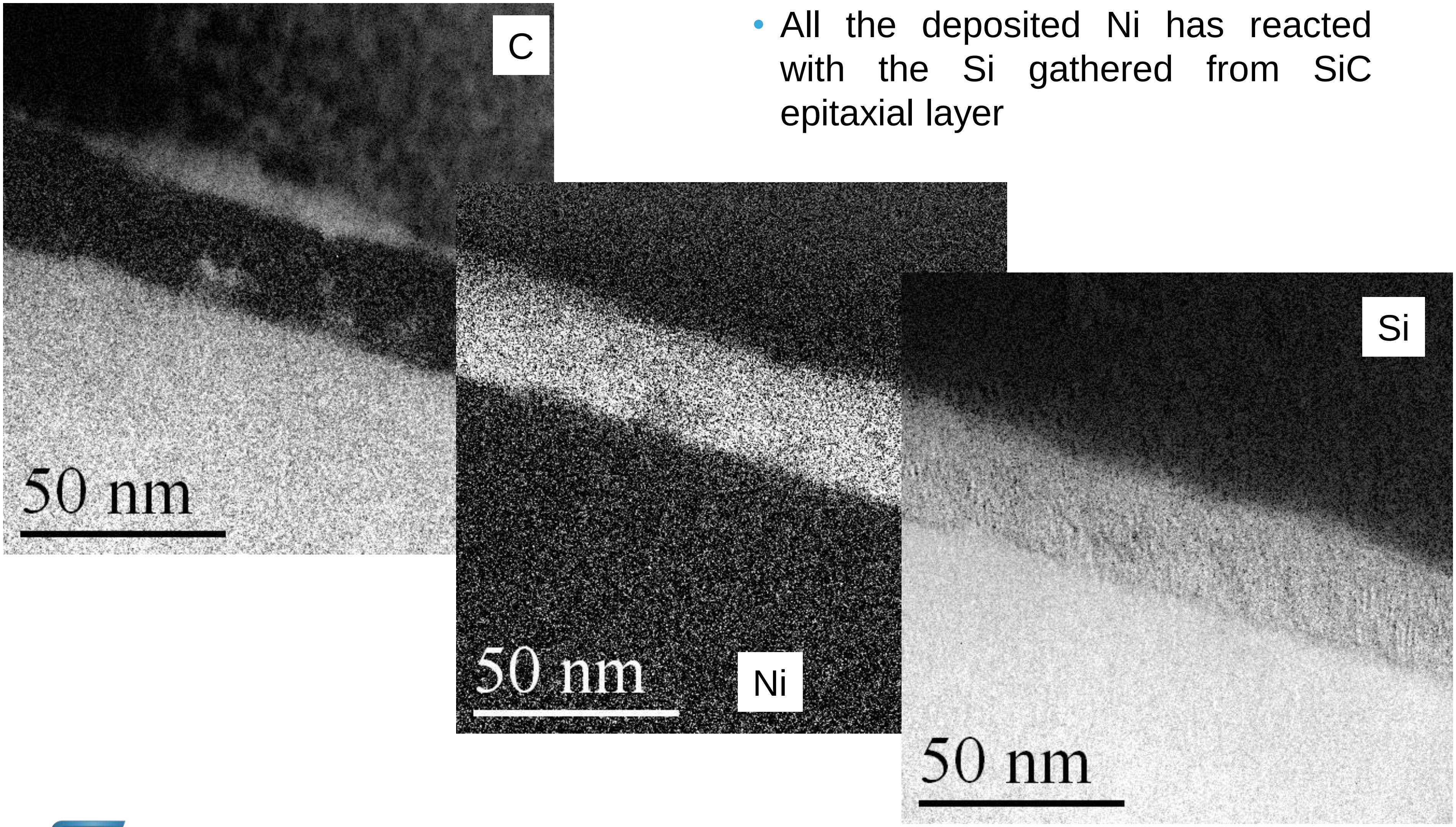
# Cross sectional TEM analyses



- The cross sectional TEM micrograph show a continuous $Ni_2Si$ layer about 20 nm thick
- Carbon clusters at the $Ni_2Si$/4H-SiC interface and on the middle-bottom portion of the $Ni_2Si$ layer are clearly visible
- These clusters are due to the segregation of residual carbon coming from the reaction between silicon and the metallic Ni



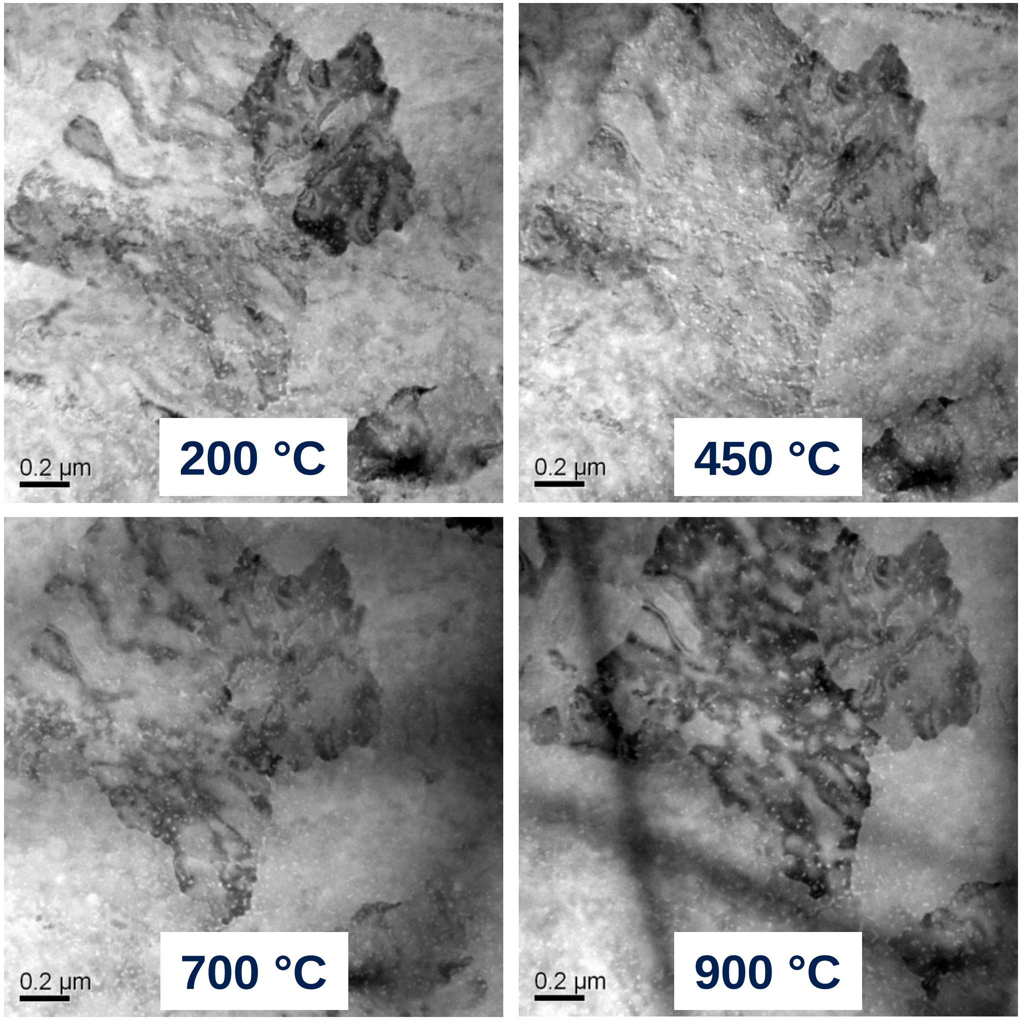
# Cross sectional EFTEM chemical maps

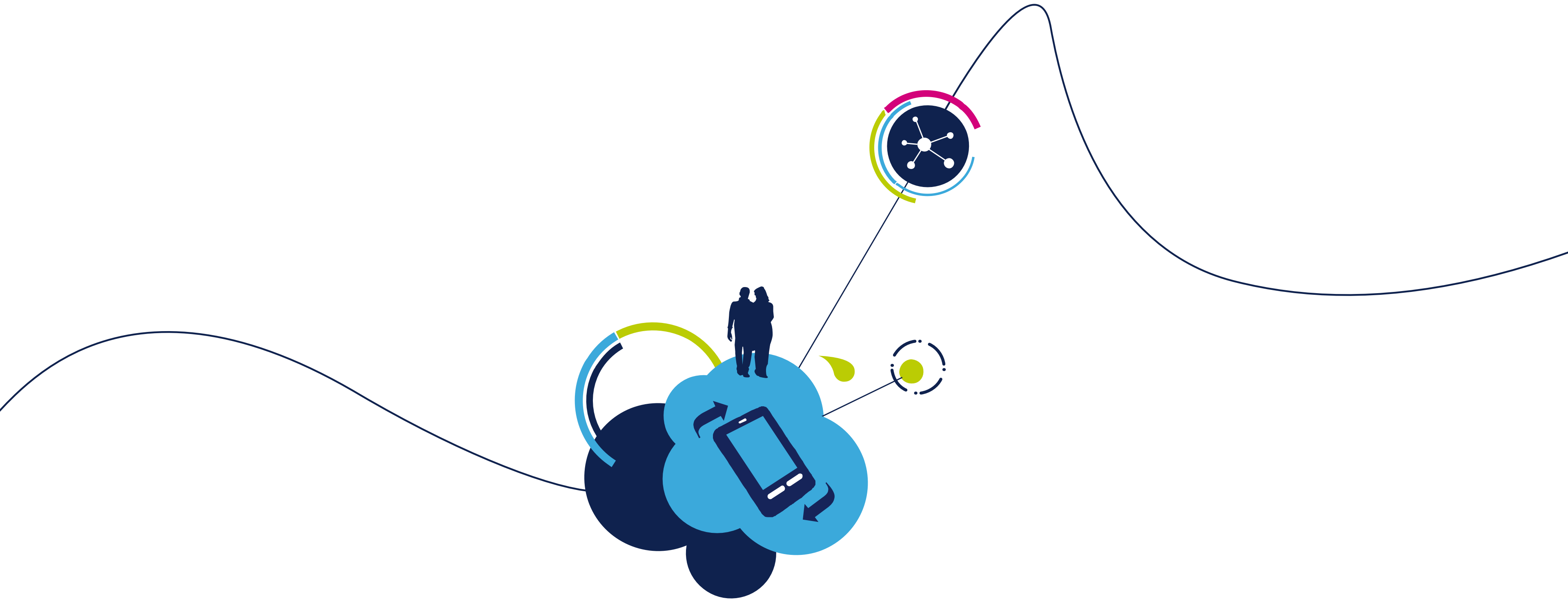



- All the deposited Ni has reacted with the Si gathered from SiC epitaxial layer

# TEM analyses with *in-situ* thermal treatment

- TEM analyses with *in-situ* treatment has been performed, rising the temperature from 200 °C up to 900 °C, with step of 50 °C and 15 minutes
- Any significant change of grains shape or grains boundaries has been observed
- The semitransparent metal barrier exhibits a good thermal stability



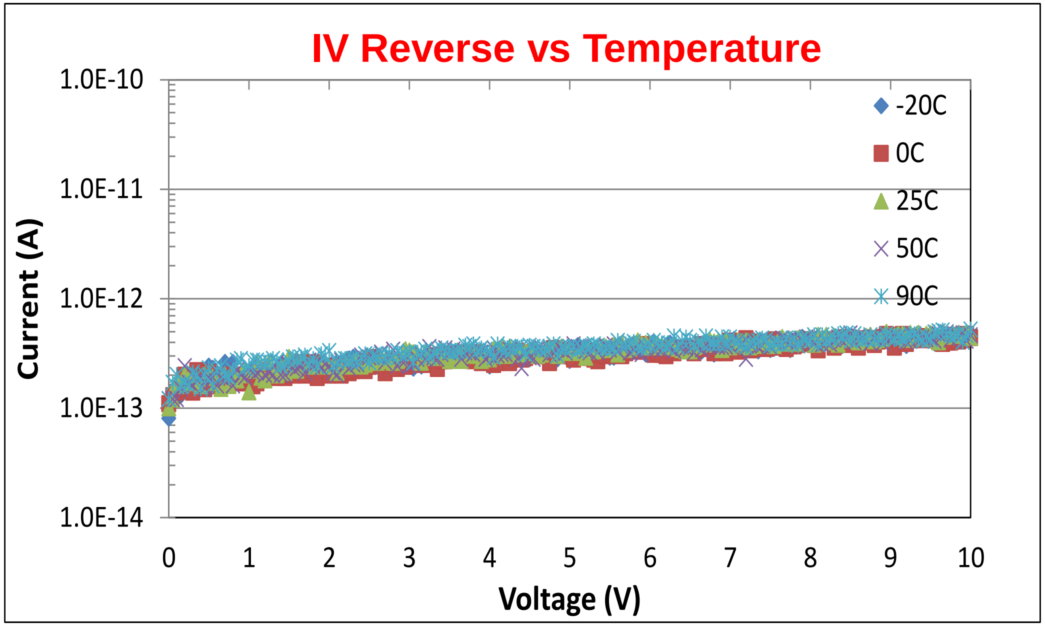


# Electro-optical characterization

# Leakage as a function of Temperature



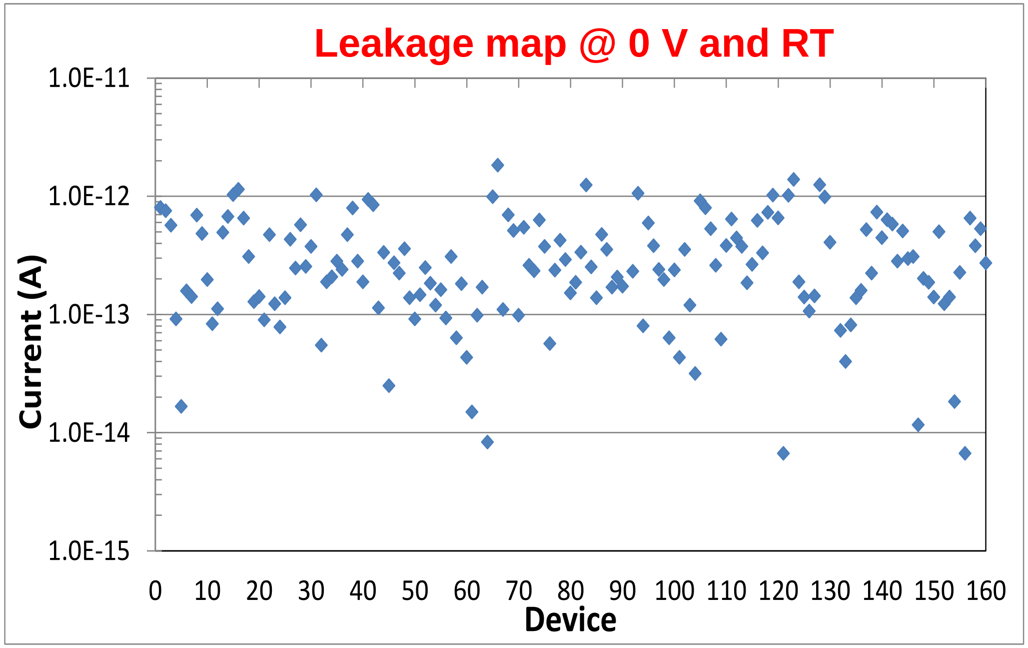
- Low leakage current (<1 pA) measured also at high temperature
- High signal to noise ratio
- High efficiency also for very low UV photocurrent levels



# Map of leakage

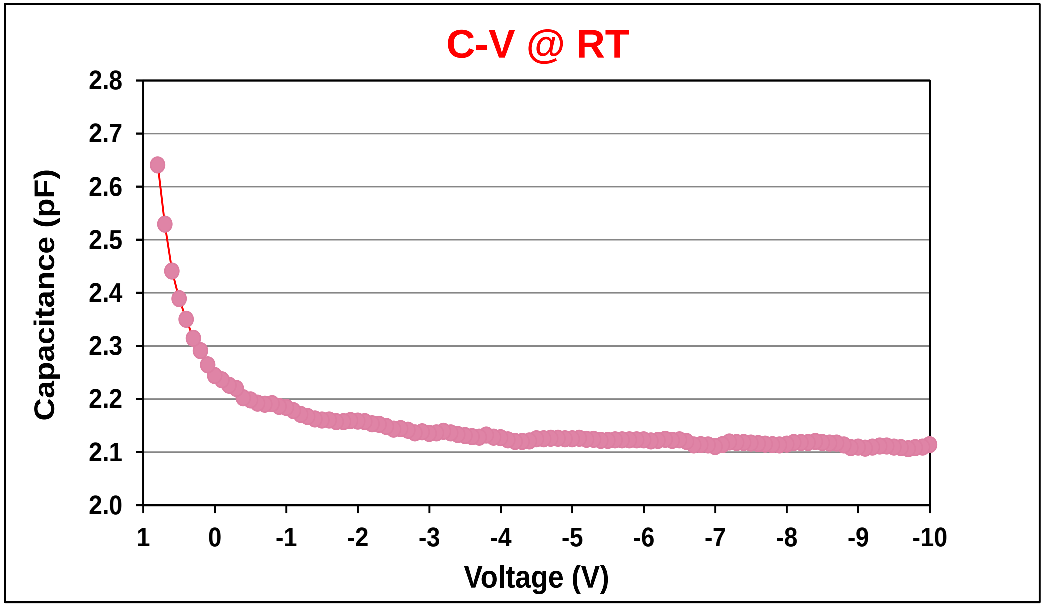


- Leakage has been measured at 0 V and room temperature on 168 devices on a wafer
- Good uniformity of performance with very low values (approximately <1 pA)



# C-V characteristic

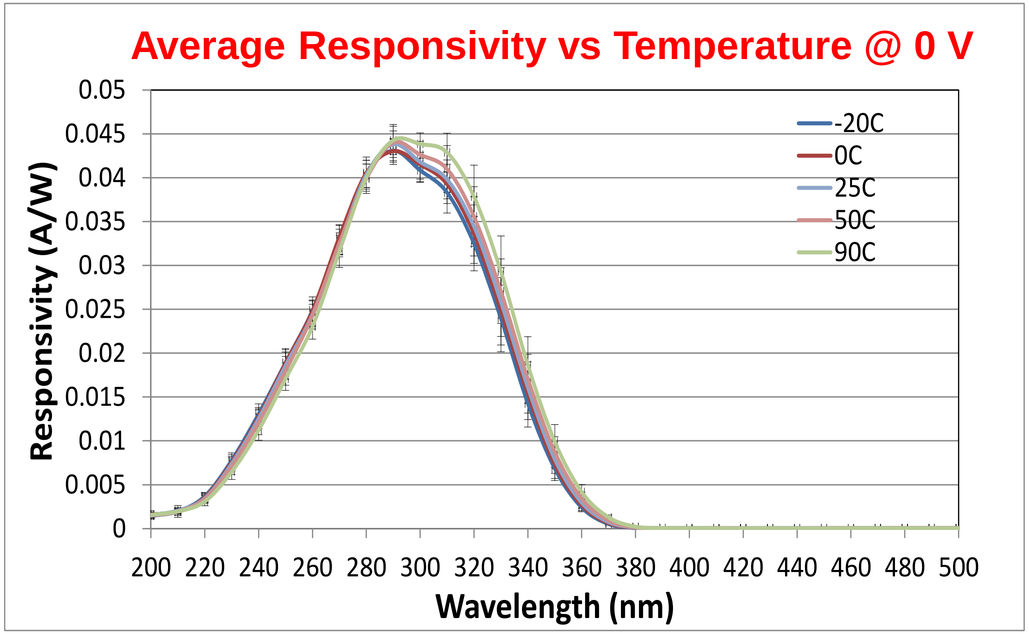
- Capacitance has been measured at room temperature as a function of the applied reverse voltage
- The capacitance does not decrease significantly when we move from 0 V to increasing reverse bias applied to the device
- The low doped epilayer is depleted at 0 V



# Responsivity @ 0 V



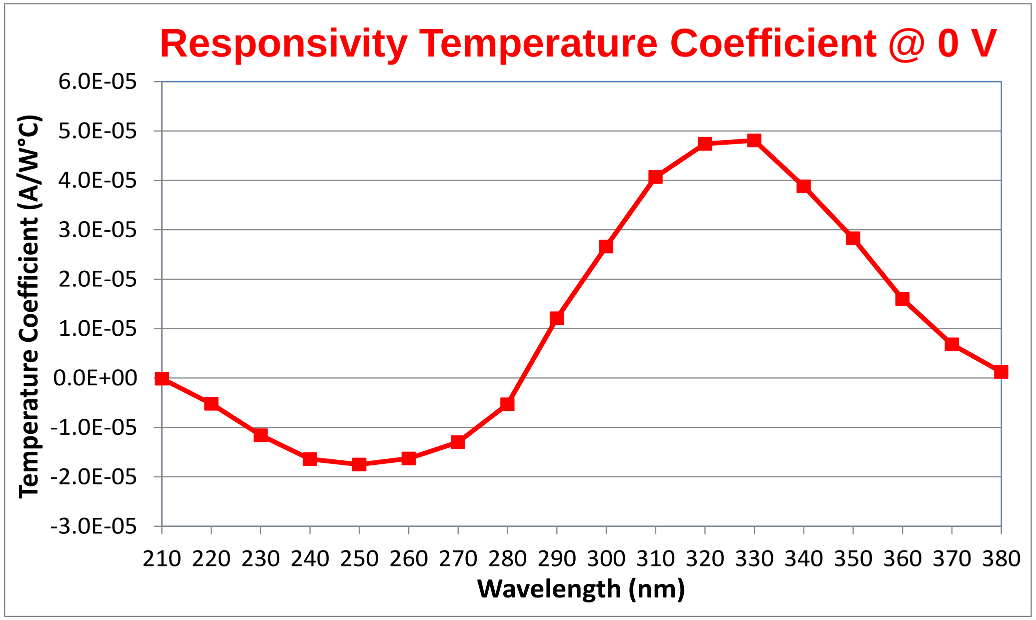
- Responsivity has been measured in photovoltaic operation condition
- Good optical response, also at low wavelengths, enabling an optimal wavelength match with erytema curve
- For a such sensitive area, a peak responsivity value in the range 0.035-0.05 A/W is required
- *Visible blindness* about $10^{-4}$



# Temperature Coefficient of Responsivity



- The Temperature Coefficient of Responsivity becomes positive above 290 nm, due to the bandgap narrowing and to the enhanced indirect band transitions above this threshold



# Conclusions



- A suitable 4H-SiC based detector operating in **photovoltaic regime** and coupled to an appropriate IC interface has been developed for the realization of an ultra-compact UVI sensor

- The use of a continuous metal silicide layer allows to obtain a good morphological **reproducibility** and **uniformity** on wafer of the electro-optical detectors performances with high wafer **yield**

- The low leakage current allows to obtain devices with very **high signal-to-noise ratio** and thus able to read with **high efficiency** very low UV photocurrent levels.

- The low thickness of the metal layer on the top side of the photodiodes ensures a **good light transmission** in the UV range enabling an optimal wavelength match with the erythema curve and thus a reliable UV Index evaluation.

# Aknowledgements

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# Thank you