POLITECNICO DI MILANO

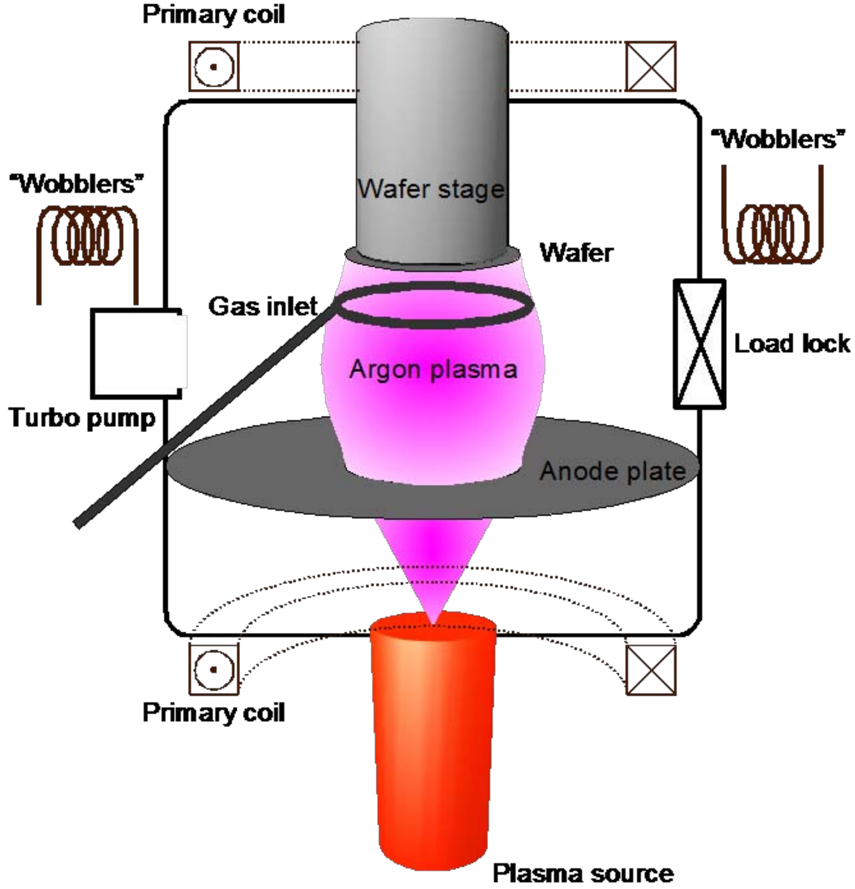
Nanophoto final meeting
Summary of WP2: nc-Si deposition

Giovanni Isella, Daniel Chrastina, Tamara Moiseev, Davide Colombo and Hans von Känel
LNESS – Politecnico di Milano - Polo Regionale di Como
Via Anzani 42
Como - Italy

Outline

- **Low-energy plasma-enhanced CVD**
  working principle and prior knowledge
- **LEPECVD for nc-Si deposition**
  motivations and requirements
- **NANOPHOTO WP2 Objectives**
  - **Optimization of film microstructure**
    Crystalline/amorphous ratio, grain size
  - **Doping studies**
    Dopant incorporation in the nc-Si layer
  - **nc-Si growth for device optimization**
    Application of the optimized growth procedures to device fabrication
  - **Plasma diagnostics**
    Plasma diagnostic by mass spectrometry and Langmuir probe

Low-energy plasma-enhanced CVD

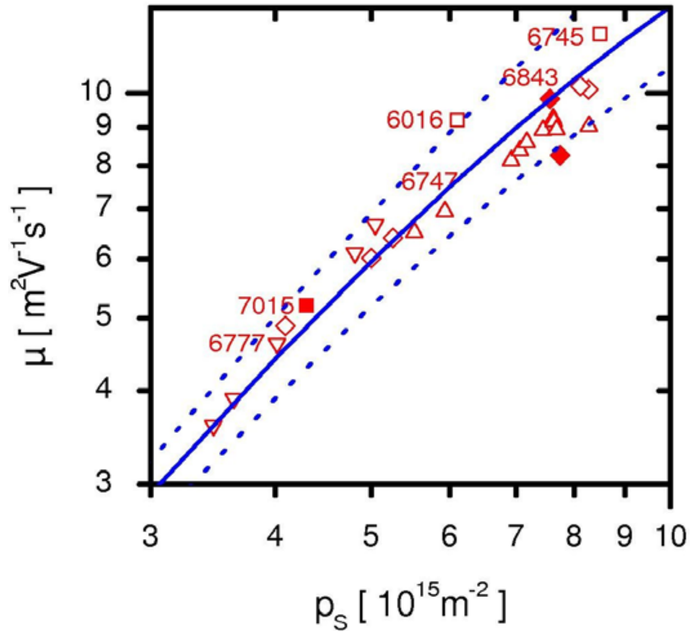


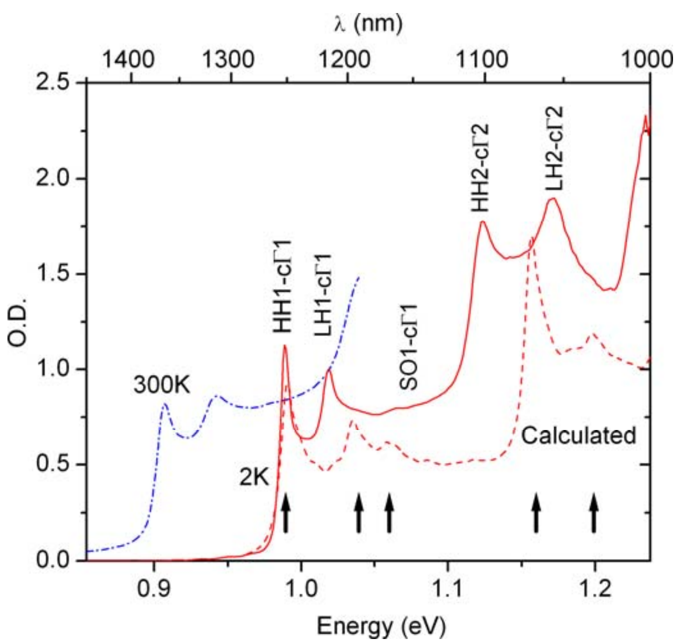
- Electrons emitted by a hot filament sustain a **DC plasma**
- Low (~10eV) ion energy
- Discharge confined by a magnetic field (~1mT)
- **High deposition rates** 5-10nm/s in "High rate" regime

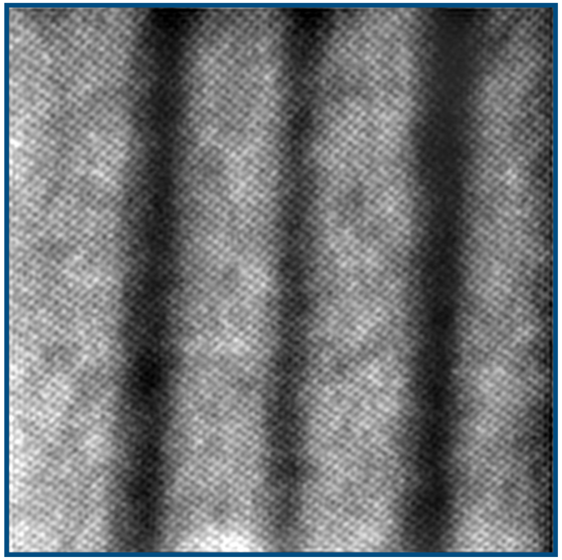
LEPECVD for SiGe heterestructures deposition

Record mobility for p-type carrier in Ge quantum wells

SiGe superlattices with excellent structural/optical properties







POLITECNICO DI MILANO

Nanophoto
final meeting
21th November 2008
Como

Prior knowledge of the LEPECVD plasma

POLITECNICO DI MILANO

A few experimental results

Mass spectrometry for Ar:H_2 plasma: **ArH^+** and **H_3^+** most abundant species

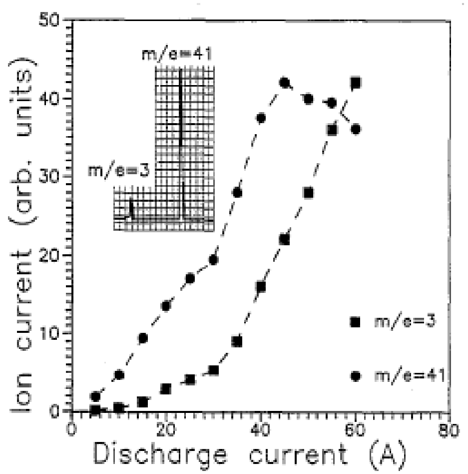


Fig. 4. The current of positively charged ions as a function of the discharge current. The inset shows the ion spectrum at a discharge current of 20 A.

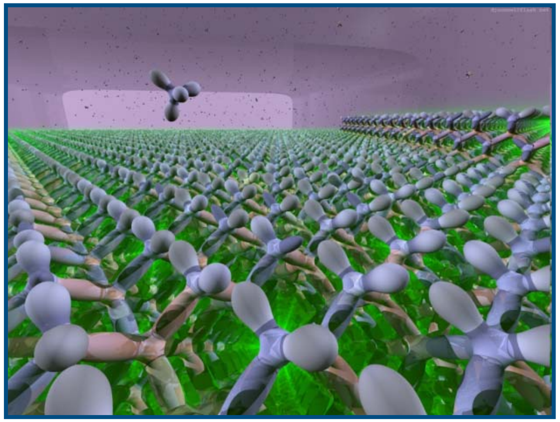
N. Korner et al. Surface and Coatings Technology 76-77, 731 (1995)

A (quite pictorial) educated guess

Ar **ion bombardment** removes the H atoms saturating the Si dangling-bonds

▼

High growth rates



nc-Si deposition by LEPECVD

Motivations

Low substrate temperature

High deposition rate 5-10nm/s for epitaxial material

Objectives

Achieveing the "right" microstructure

Dopant incorporation

Optimized procedure for device fabrication

Plasma monitoring

POLITECNICO DI MILANO

nc-Si deposition by LEPECVD

A wide spectrum research

Approx **120 depositions** performed on **five** different substrates:

Si(100) **SiO_2/Si(100)** **glass**
ITO/glass **ZnO/glass**

Varied growth parameters:

SiH_4 dilution (%): $\frac{[SiH_4]}{[H_2]+[SiH_4]}$

SiH_4 flux: 0.5 to 20sccm

Plasma density (through the confining magnetic field)

Substrate temperature: 200-300°C

POLITECNICO DI MILANO

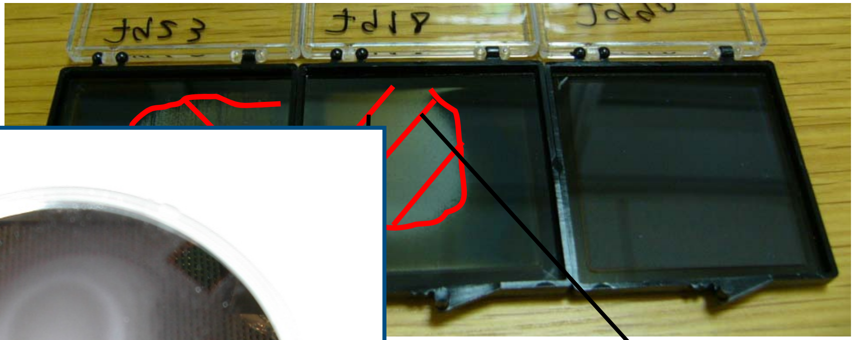
Nanophoto
final meeting
21th November 2008
Como

Film adhesion

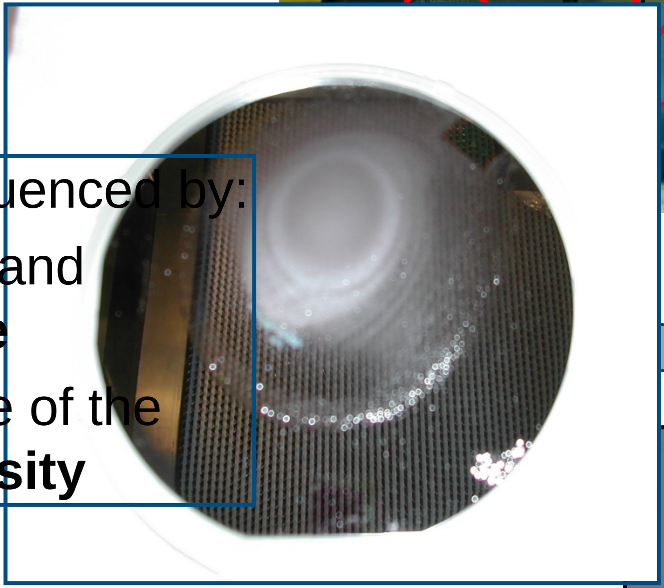
Under conditions developed for epitaxial Si deposition

▼

The film is **not sticking**! Extensive **flaking** due to internal stress



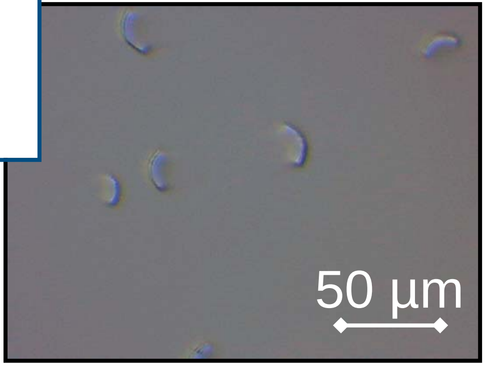
0.6mT 0.5mT



Adhesion is influenced by:

Substrate **type** and **temperature**

Strong influence of the **plasma density**



POLITECNICO DI MILANO

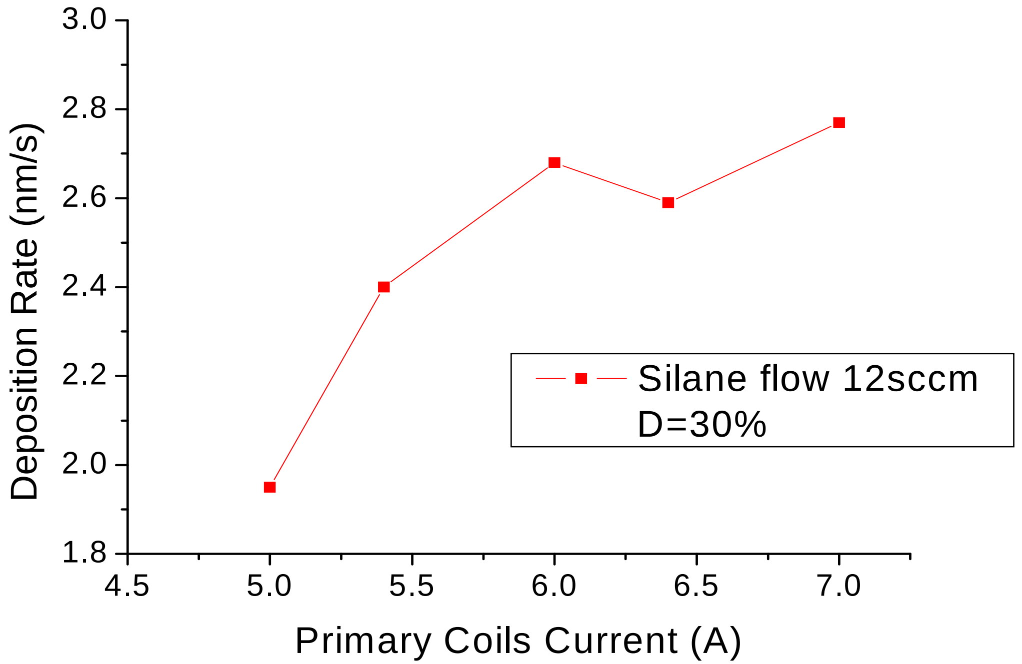
Film adhesion: role of the confining magnetic field

POLITECNICO DI MILANO

Reduction of the confining magnetic field

▲ improved film adhesion

▼ growth rate reduction

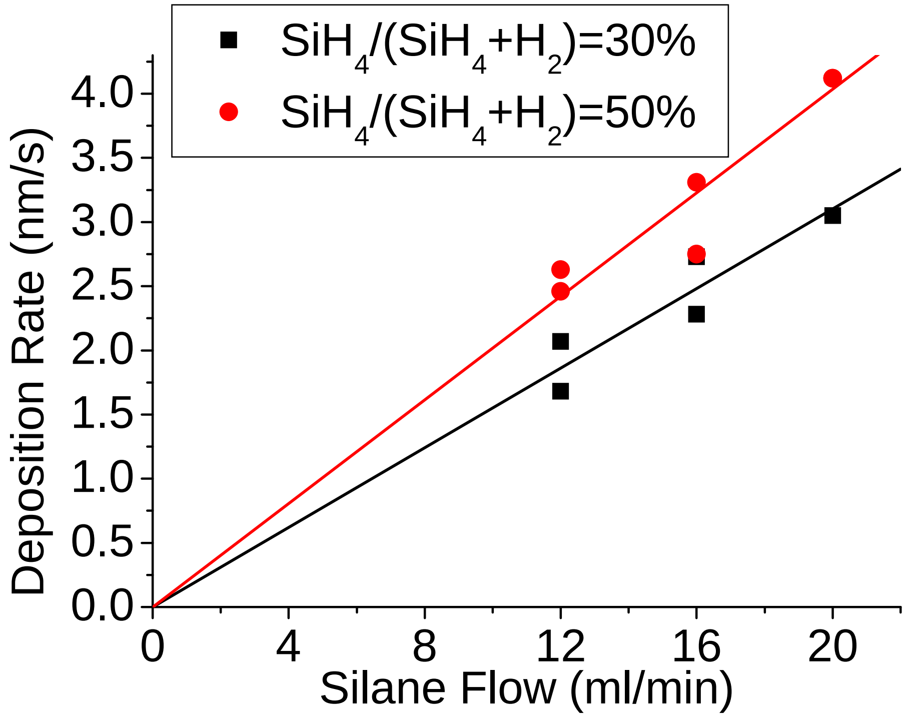


Confining field of 0.5mT (5A current) ensures a sufficiently **good adhesion** for all the substrates considered

"H-etching" of nc-Si film

POLITECNICO DI MILANO

Higher hydrogen content in the feed gas reduces the deposition rate



PRL 100, 046105 (2008) PHYSICAL REVIEW LETTERS week ending 1 FEBRUARY 2008

Thermal-Hydrogen Promoted Selective Desorption and Enhanced Mobility of Adsorbed Radicals in Silicon Film Growth

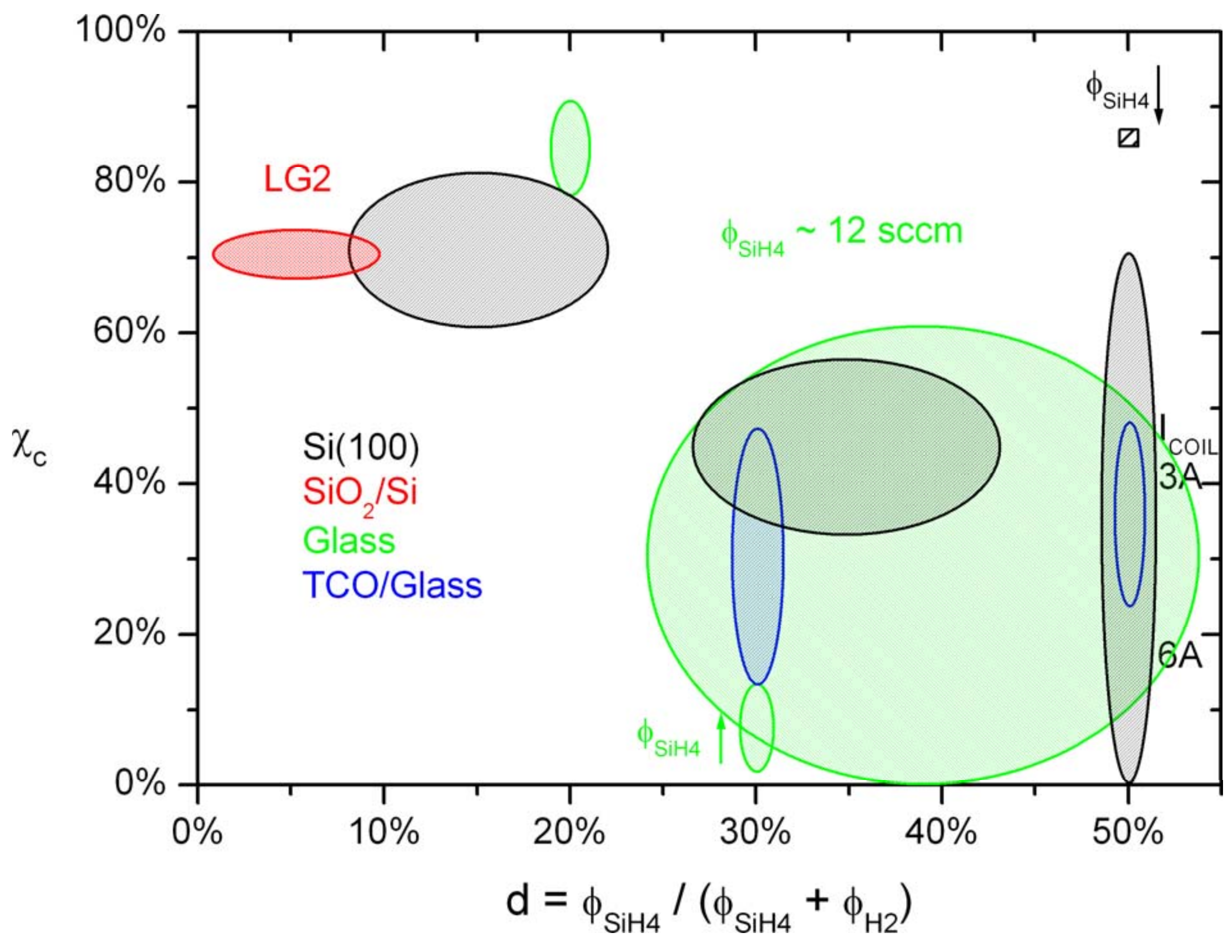
S. Cereda, F. Zipoli, M. Bernasconi, Leo Miglio, and F. Montalenti*

L-NESS and Dipartimento di Scienza dei Materiali della Università degli Studi di Milano-Bicocca, Via Cozzi 53, I-20125 Milano, Italy

(Received 17 July 2007; published 1 February 2008)

Crystalline/amorphous fraction optimization

POLITECNICO DI MILANO



Nanophoto
final meeting
21th November 2008
Como

Crystalline/amorphous fraction optimization

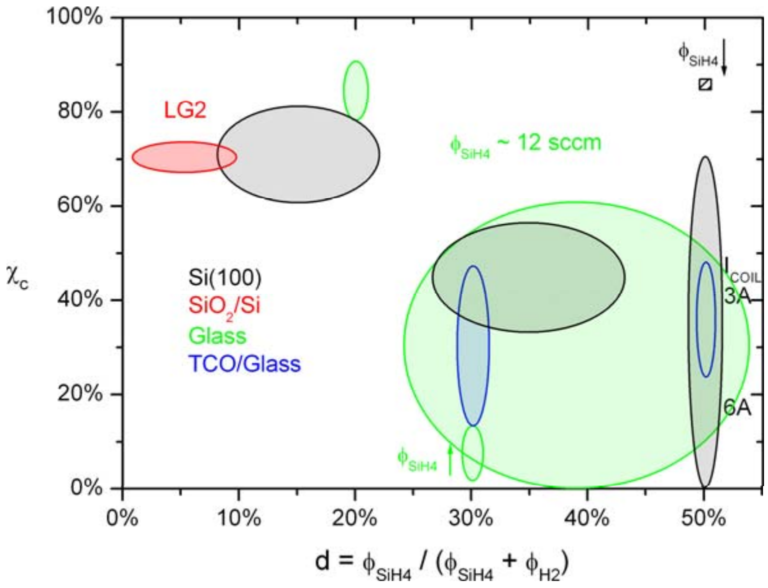
POLITECNICO DI MILANO

Great variability of the χ_c especially around 30-40%

The "transition type" nc-Si is obtained at d value much higher than in radio-frequency PECVD for all substrate type

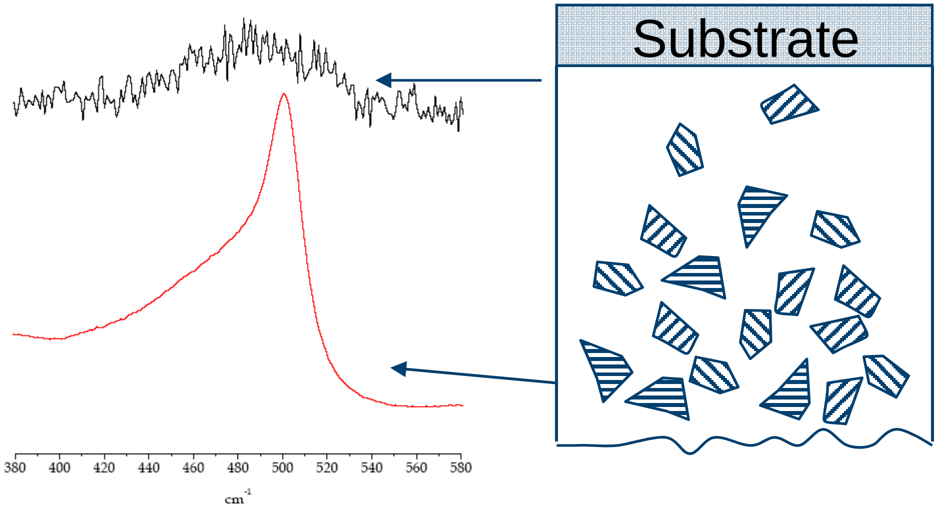
▼

The specific character of the plasma might play a relevant role



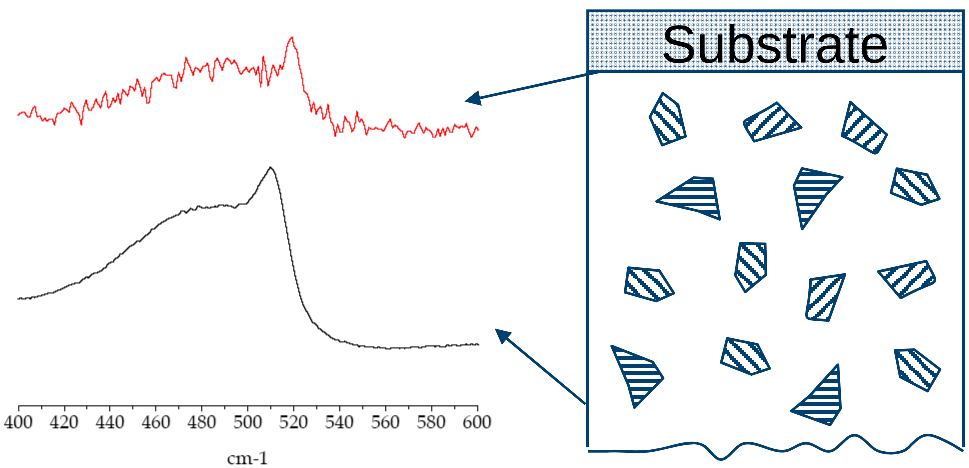
Silane flow and uniformity in the growth direction

SiH$_4$ = 20 sccm



Silane Concentration
SiH$_4$/(SiH$_4$+H$_2$)= 30%

SiH$_4$ = 12 sccm



Raman Spectra by A. Le Donne UNIMIB

WP2- Task 1 Optimization of film microstructure

POLITECNICO DI MILANO

- Process window to obtain "transition type" nc-Si
  SiH_4 dilution ≈ 30%
  SiH_4 flux ≈ 12sccm
  Confining field ≈ 0.5mT (electron density 10^{16} m^{-3})

- Good adhesion on all substrate investigated

- Good uniformity in the growth direction

- Bad "in plane" uniformity

Doping of nc-Si layer

Requirements for p-type layer in thin film Si solar cell

Thin (30nm) and highly conductive

I High dopant **incorporation**

II High dopant **activation**

III High **crystallinity**

Things are made more complex by ...

I incorporation does not depend monotonically on the dopant concentration in the feed gas

II the low substrate temperature does not favour activation

III Boron favours amorphization

Doping of nc-Si layer : p-type layer

Two TCOs investigated

ITO – not compatible with H-plasma

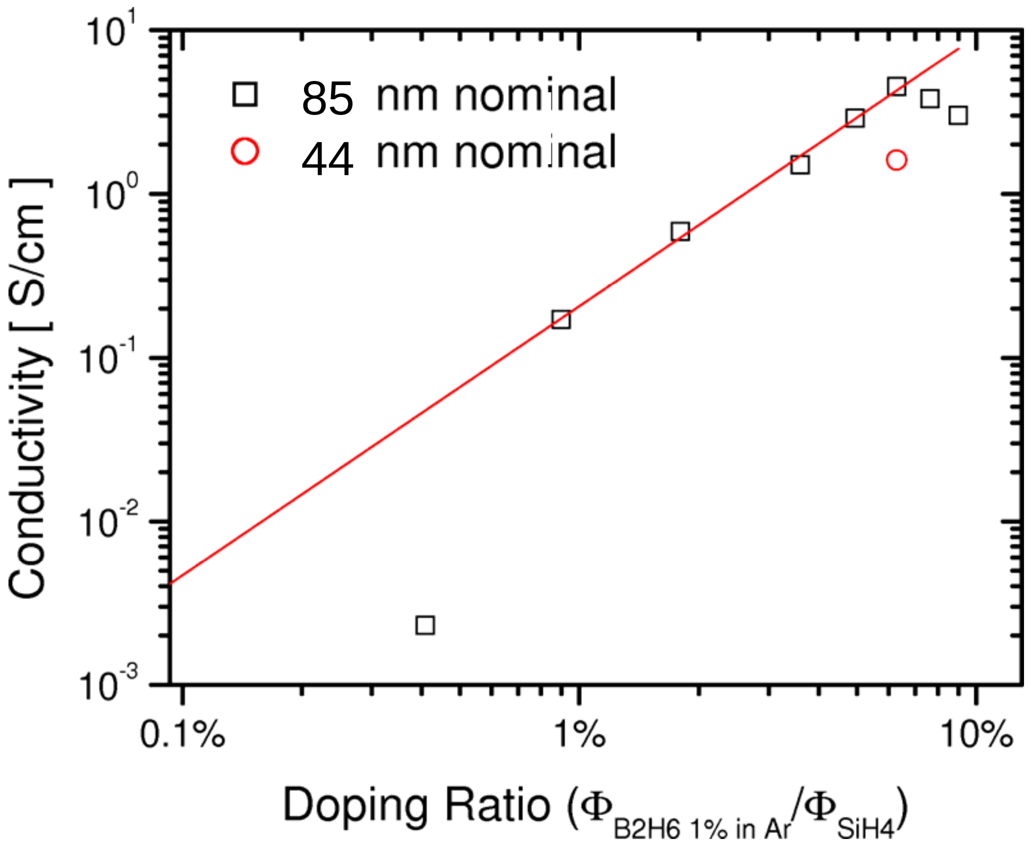
ZnO – good compatibility

Increased crystallinity

SiH_4 concentration = 1%

SiH_4 flux = 0.5sccm

Conductivity as a function of the Doping Ratio = B_2H_6/SiH_4



Highest conductivivity for DR=6.3%

(DR<1% for PECVD)

POLITECNICO DI MILANO

Nanophoto
final meeting
21th November 2008
Como

Doping of nc-Si layer : n-type layer

Less critical than p-type

I Not necessarily **thin**

II High **crystallinity**

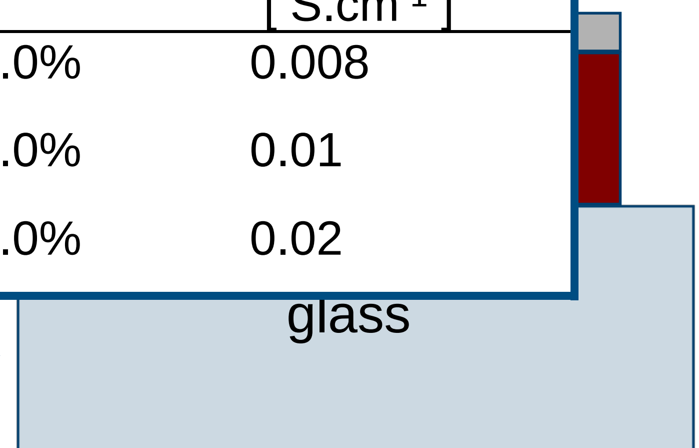
III Needs to be grown on the **absorbing layer** (crystallinity around 40-50%)

80nm n-type layer deposited in a different reactor

Sample	*DR*	σ_{RT} [S.cm^{-1}]
8151 / 56404	2.0%	0.008
8152 / 56405	5.0%	0.01
8153 / 56406	1.0%	0.02

Absor
op

Substrate:glass without TCO for electrical measurements



WP2- Task 2 Doping studies

POLITECNICO DI MILANO

p-type layer

- State-of-the-art conductivity obtained
- Conductivity dependence on the doping ratio still under investigation

n-type layer

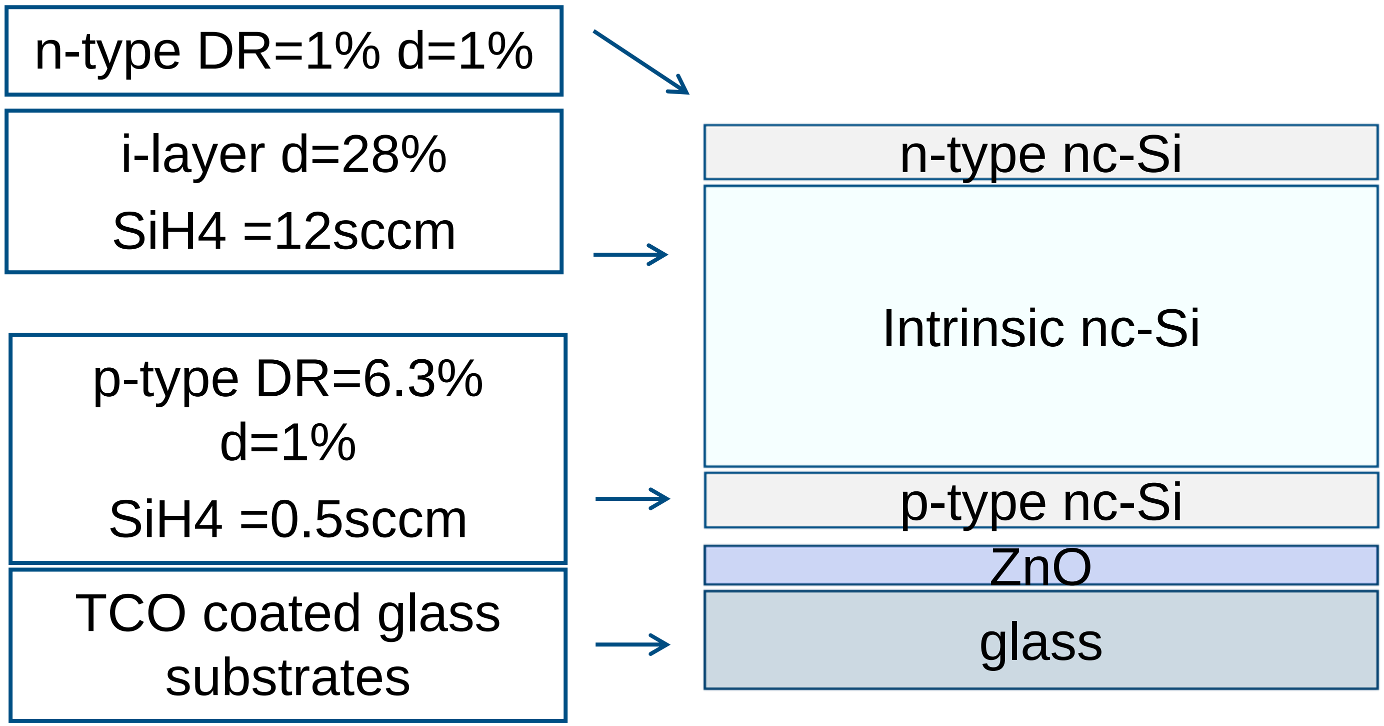
- Conductivity sufficient for back-side contact
- Higher phosphine concentration in the doping mixture might be required for further improvement

POLITECNICO DI MILANO

Nanophoto
final meeting
21th November 2008
Como

nc-Si growth for device optimization

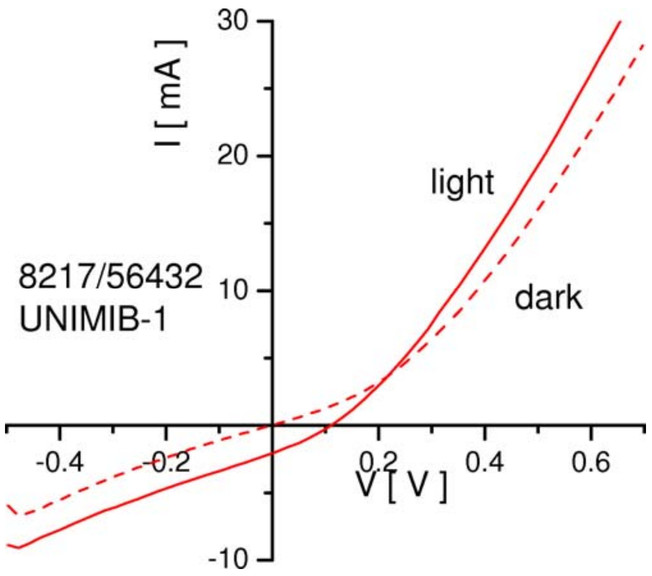
Putting all the pieces together …



The result is …

nc-Si growth for device optimization

... much worse than the sum of the different components!



Poor photovoltaic performances:

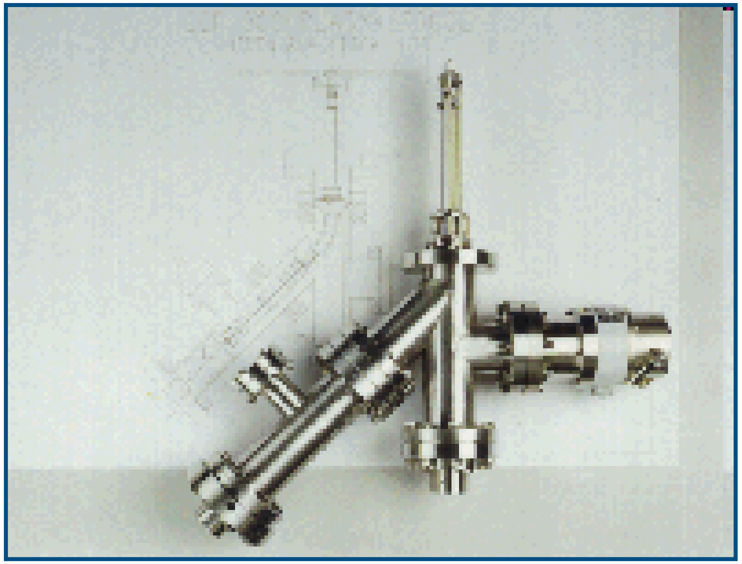
•Low parallel and high series resistance related to fabrication issues

•Non optimized doped/undoped interfaces

•Recombination centers in the absorbing layer

Plasma Monitoring: Mass spectrometry and Langmuir probe measurements

POLITECNICO DI MILANO



EQP 300 form Hiden Analytics

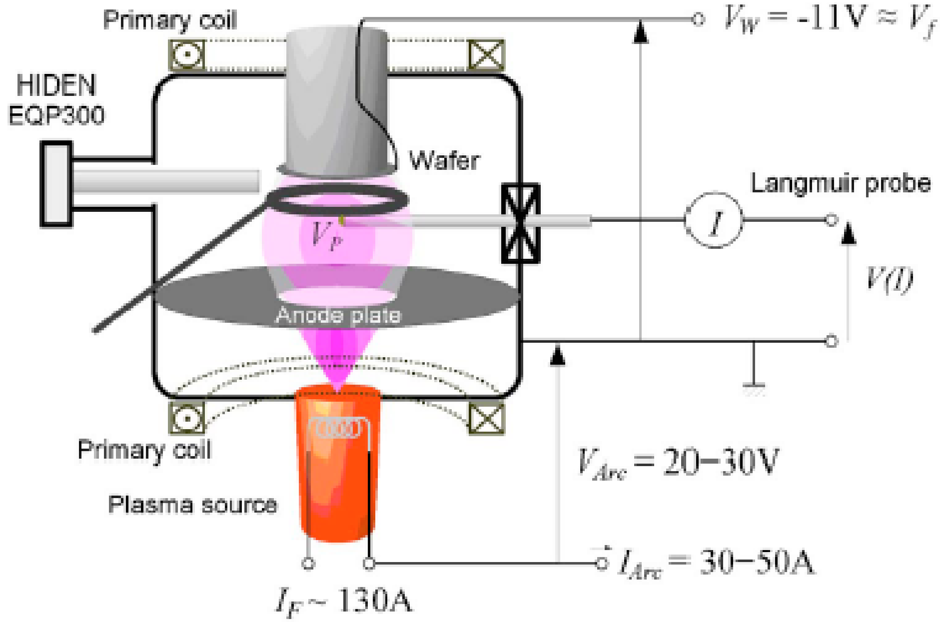
Mass/energy analyzer for ions and neutrals

EQP300 specially designed to:

monitor a DC plasma avoiding damage by the **1kW power** of the discharge

perform measurements at **different** radial **position** in the reactor

Plasma Monitoring: Mass spectrometry and Langmuir probe measurements



Energy integrated ion density measured in secondary ions mass spectroscopy (**SIMS**) mode

Neutral density measured in threshold ionization mass spectroscopy (**TIMS**) mode

Electron and ion current and densities measured by Langmuir probe

Nanophoto
final meeting
21th November 2008
Como

NANOPHOTO WP2 Objectives

POLITECNICO DI MILANO

+	**Optimization of film microstructure** Crystalline/amorphous ratio, grain size
++	**Doping studies** Dopant incorporation in the nc-Si layer
-	**nc-Si growth for device fabrication** Application of the optimized growth procedures to device fabrication
++	**Plasma diagnostics** Plasma diagnostic by mass spectrometry and Langmuir probe