Optical Constants of $Ni_{1-x}Pt_x$ and $Ni_{1-x}Pt_xSi$ for Inline Metrology of Ohmic Contacts

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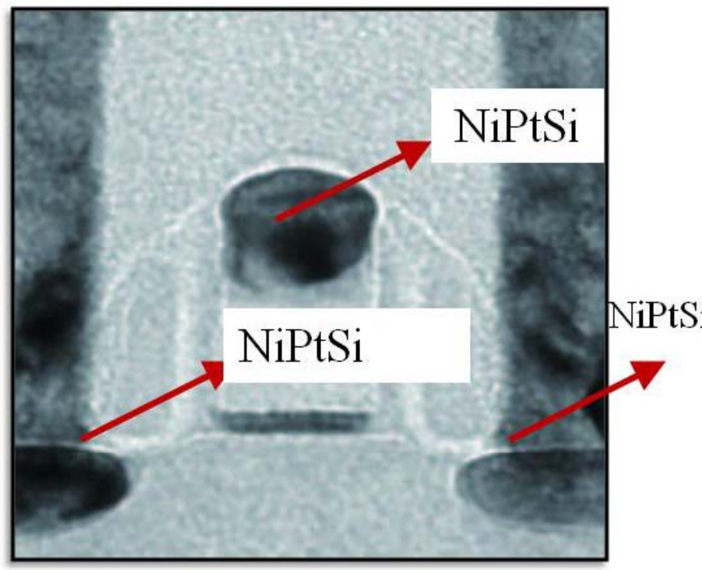
Variable Angle Spectroscopic Ellipsometry (VASE)



NSF: DMR-11104934

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Samples: Demkov (UT Austin), Alpay (UConn), MTI (LAO), SurfaceNet (NiO), IBM, Ohio State

Flat & uniform films, at least 5 by 5 mm^2,
low surface roughness, films on single-side polished substrate
Email: zollner@nmsu.edu

http://ellipsometry.nmsu.edu

Units of Optical Constants

- **Wavelength λ and photon energy E**

  Wavelength: Specified in nm, μm, or Å

  Photon energy: Specified in eV

  $E=\hbar\omega=hc/\lambda$ (633 nm equals 1.96 eV)

- **Dielectric function, refractive index, and conductivity**

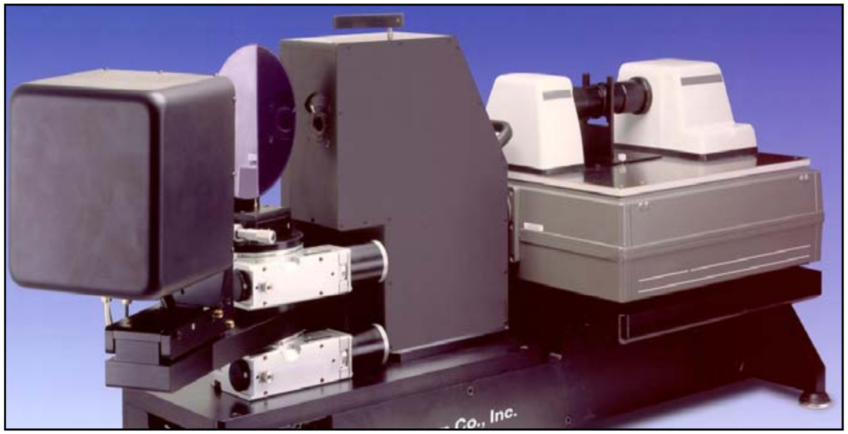
  Complex dielectric function: $\varepsilon=\varepsilon_1+i\varepsilon_2$

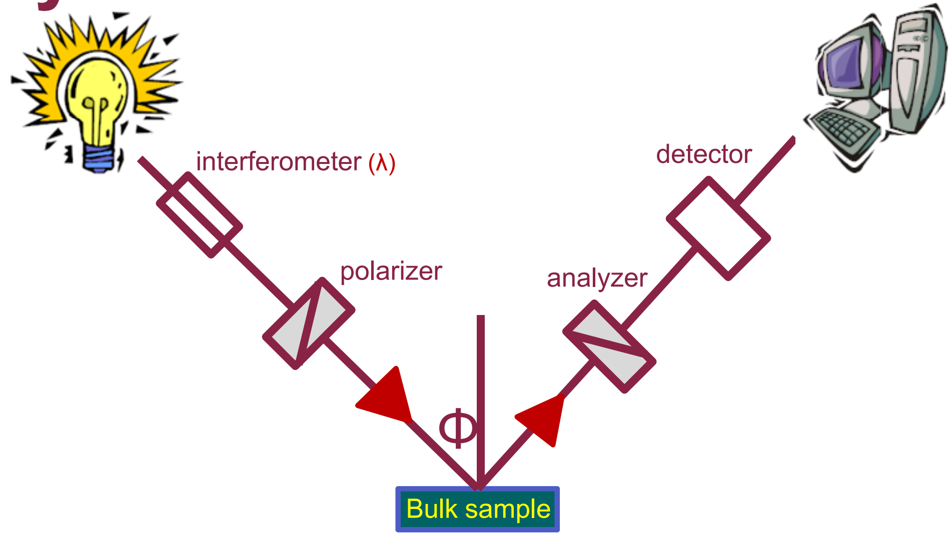
  Complex refractive index: $n=N+ik$

  Optical conductivity: $\sigma=\sigma_1+i\sigma_2=-i\varepsilon_0 E(\varepsilon-1)/\hbar$

- **For a metal, n and e diverge in the infrared due to the Drude response of free carriers. This divergence is avoided by the optical conductivity.**

Spectroscopic Ellipsometry





Spectral range: 125 nm – 40 µm

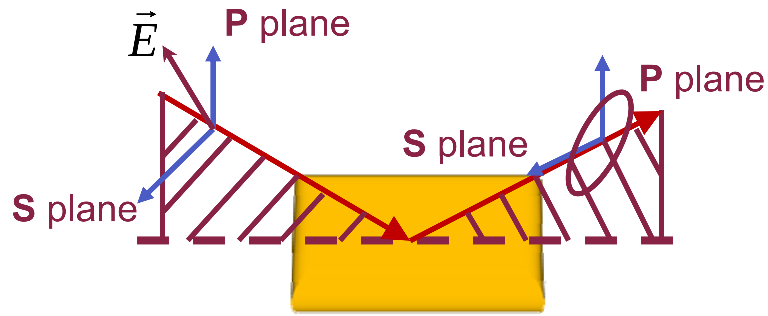
$$\rho = \frac{R_p}{R_s} = \frac{E_{rp}}{E_{ip}} \cdot \frac{E_{is}}{E_{rs}} = \tan \Psi \, e^{i\Delta}$$

$$\langle \tilde{n} \rangle^2 = \sin^2 \phi \left[1 + \tan^2 \phi \cdot \left(\frac{1-\rho}{1+\rho} \right)^2 \right]$$

$$\tilde{n} = n + ik$$

$$\tilde{\varepsilon} = \varepsilon_1 + i\varepsilon_2$$

$$\varepsilon_1 = n^2 - k^2 \qquad \varepsilon_2 = 2nk$$

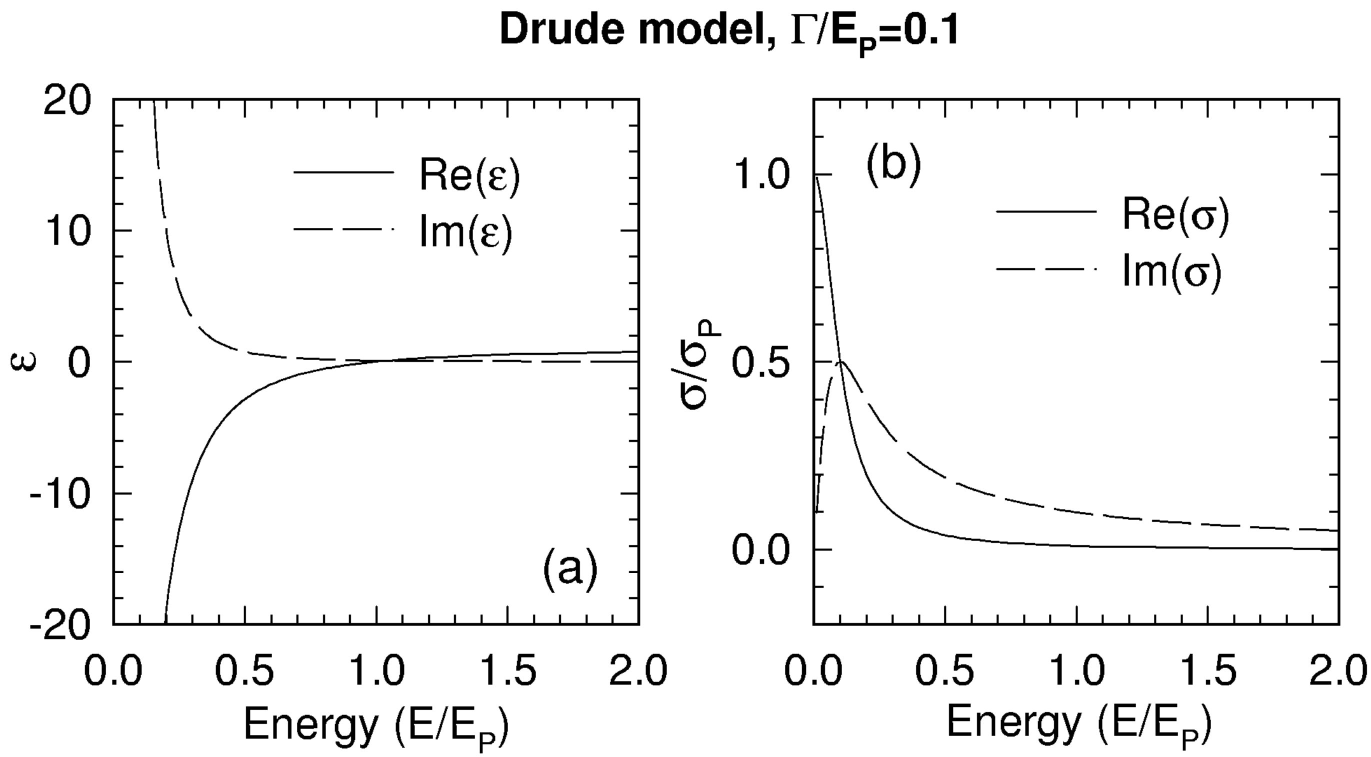


Optical conductivity

$$\sigma_1 = E\varepsilon_0\varepsilon_2$$

$$-\sigma_2 = (1-\varepsilon_1)E\varepsilon_0$$

Dielectric function and optical conductivity



σ_1: Conductivity, absorption $\sigma_0 = \frac{ne^2\tau}{m} = \frac{\varepsilon_0}{\hbar}\frac{E_P^2}{\Gamma}$

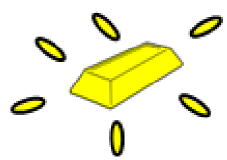
σ_2: Phase shift, dispersion

σ_2 has maximum at $E=\Gamma$

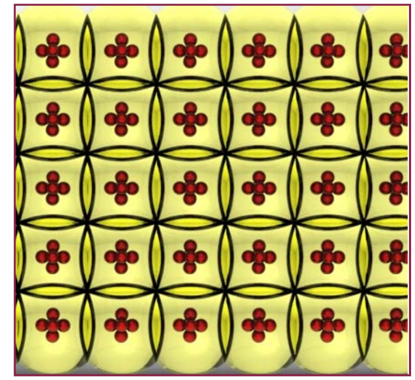
σ_1 and σ_2 cross at $E=\Gamma$, value is $\sigma_0/2$

Drude-Lorentz Model for Optical Constants of Metals

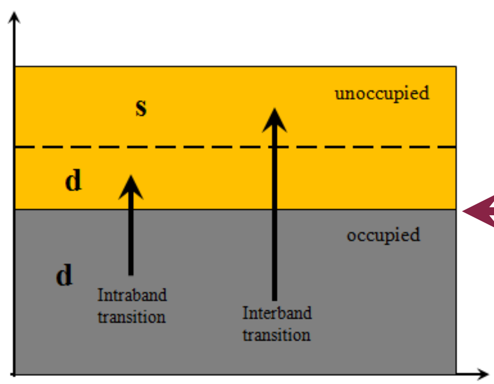
High reflection Coefficient



Outermost electrons shared by all the surrounding atoms



No band gap: almost any frequency of light can be absorbed.



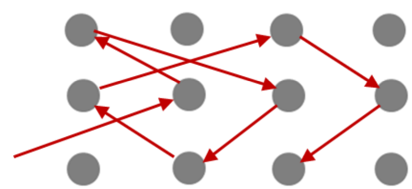
E Fermi

For metal films k≠0, ε is complex, decomposed into two components

$$\varepsilon = \varepsilon_{FCA} + \varepsilon_{bound}$$

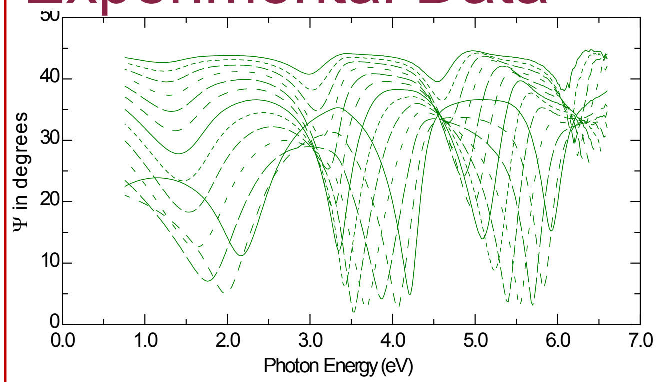
Free carriers (Drude)

Bound carriers (Lorentz)



Ellipsometry Data Analysis

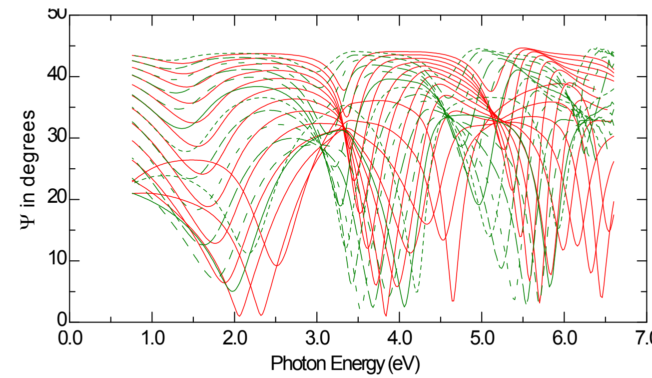
Experimental Data



Build a model

2	Layer 2	t_2
1	Layer 1	t_1
0	substrate	∞

Generated Data



Compare Exp. And Gen. data

Match ??

NO

Change model parameters

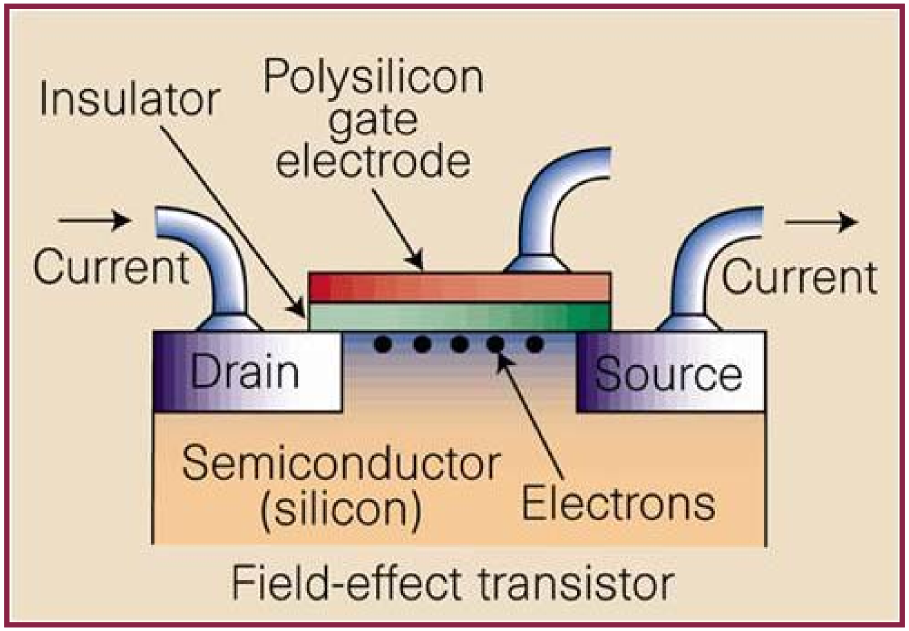
YES

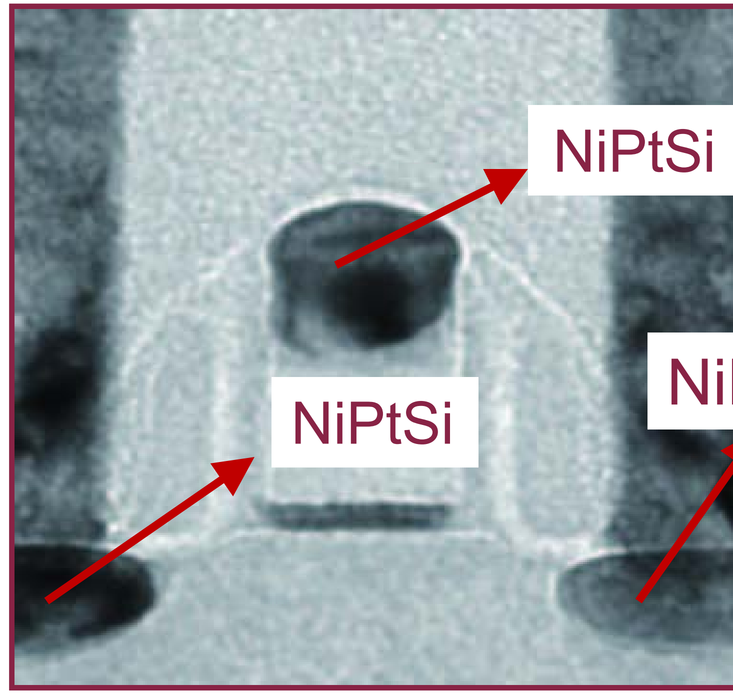
- Well known material (Si, SiO_2)
  Tabulated data

- New material (NiPt, NiPtSi)
  Set of oscillators
  Solve numerically

Motivation: Metrology of NiSi for Ohmic Contacts

MOSFET: metal–oxide–semiconductor field-effect transistor



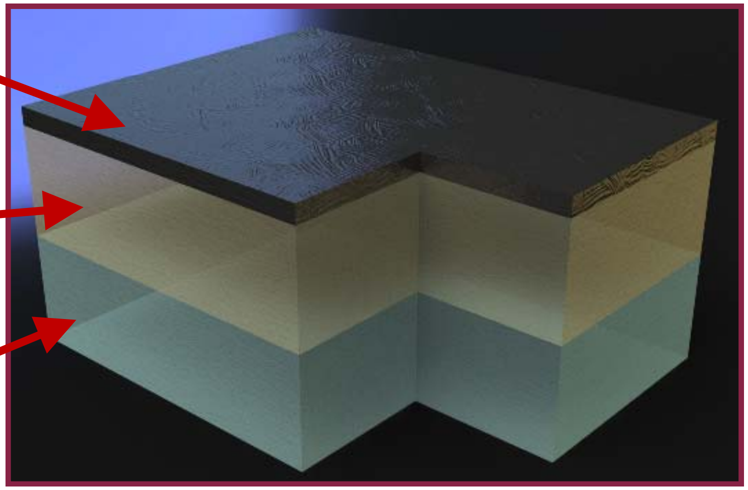


- Low resistivity
- Low formation temperature
- Low Si consumption

32 nm SOI CMOS (Greene *et al.*)
industrial self-aligned silicide process

$Ni_{1-x}Pt_x$ alloy samples and experimental details

- Films were deposited using **Physical Vapor Deposition (PVD)**.
- Different Pt concentrations (0%, 10%, 15%, 20%, 25%)
- with/without annealing (500˚C for 30 s)
- Low surface roughness.
- 300 mm wafers.
- Rough backside.

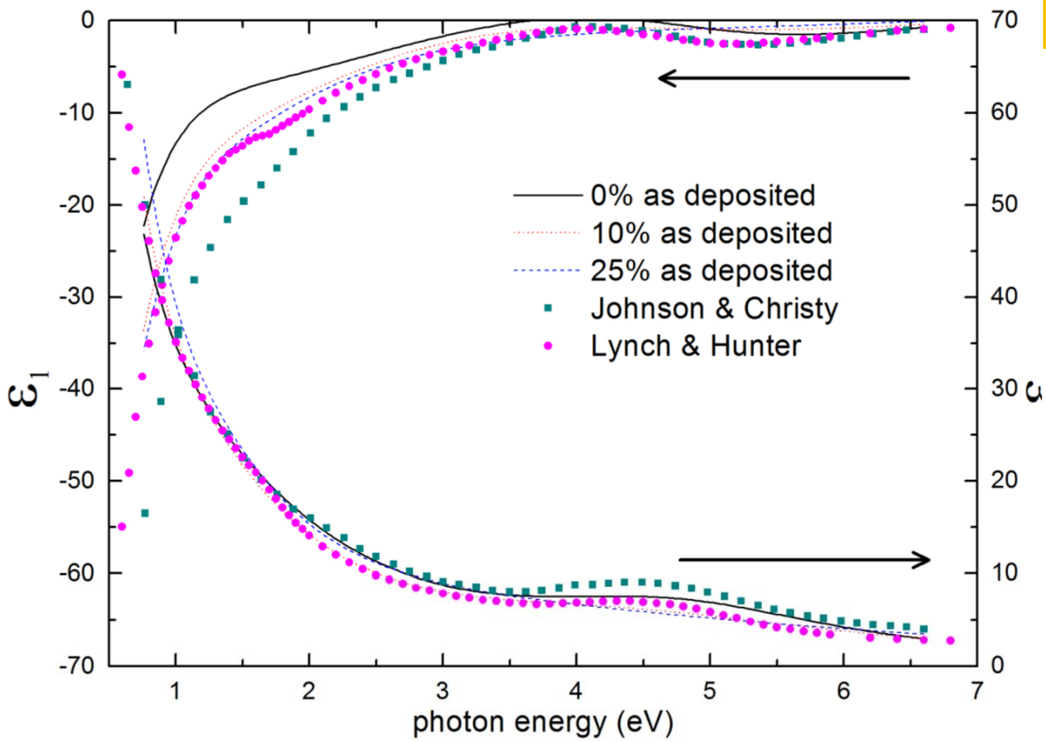


- Room temperature measurements.
- **Fourteen angles of incidence (20˚ to 80˚, steps of 5˚)**
- Broad photon energy range (0.6 to 6.6 eV), 20 meV steps, 300 data points per angle. **2 nm resolution (1 mm slits)**
- Each measurement lasts **24 hours.**

Optical constants of Ni and $Ni_{1-x}Pt_x$ alloys

- Dielectric Function

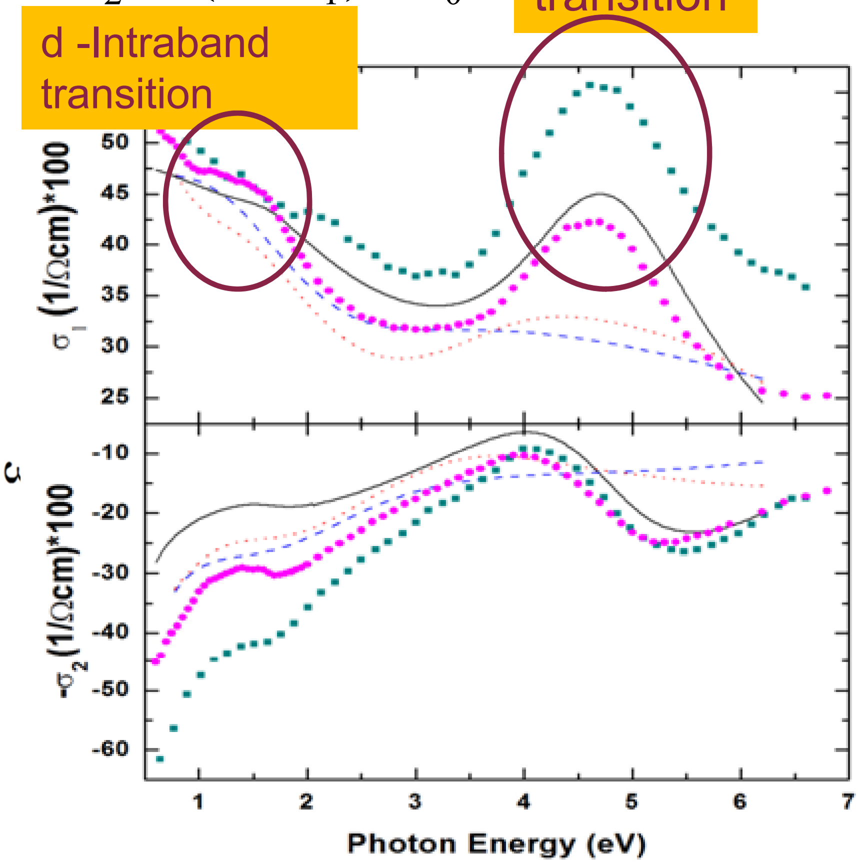
ε_2 **Describes absorption**



- Optical Conductivity

$$\sigma_1 = E\varepsilon_0\varepsilon_2$$

$$-\sigma_2 = (1-\varepsilon_1)E\varepsilon_0$$



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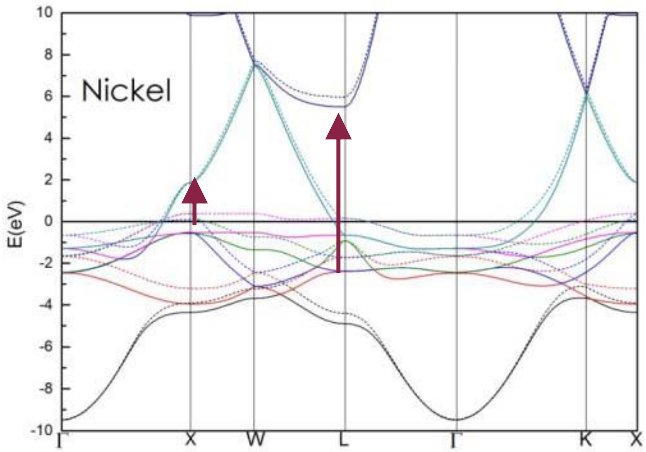
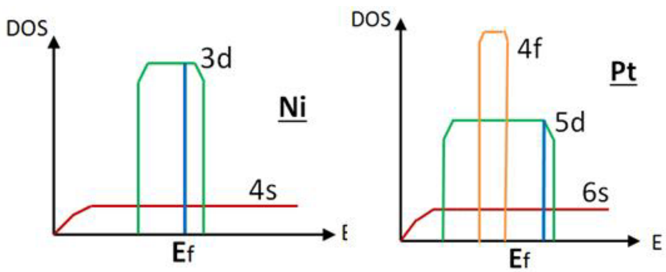
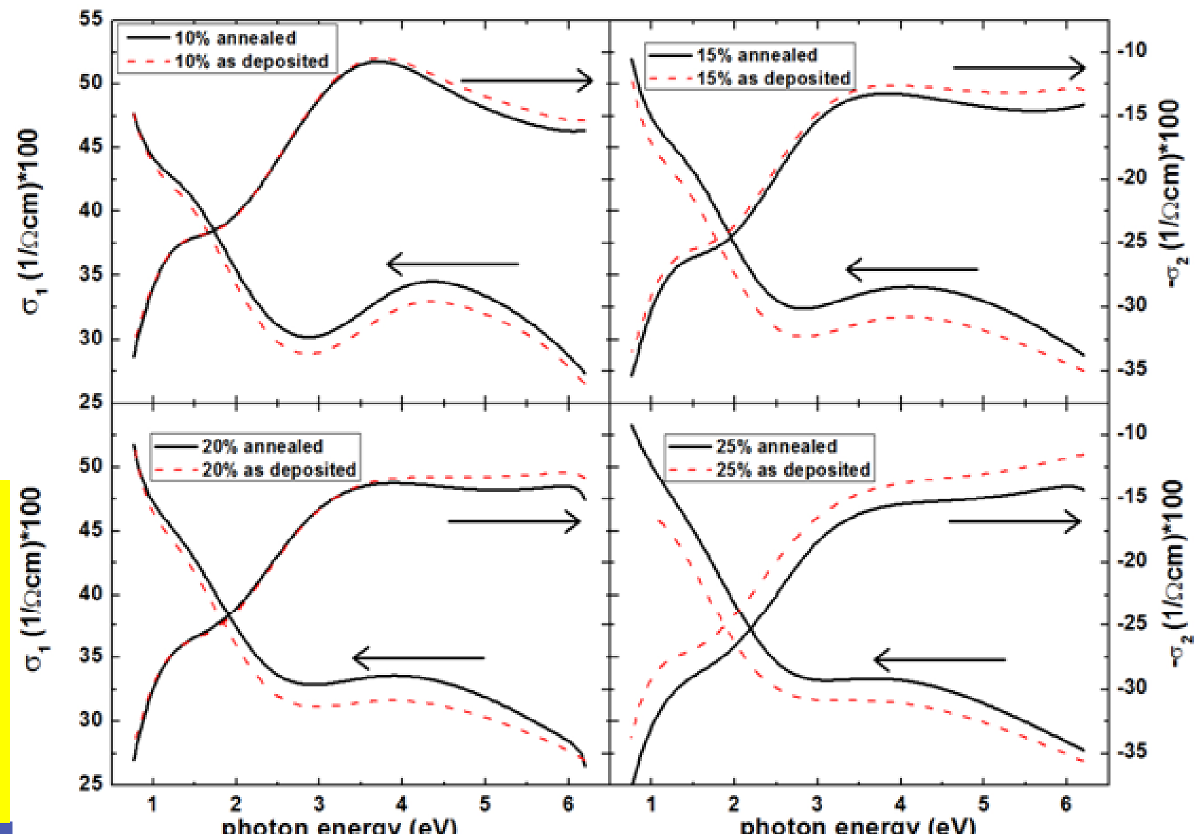
Optical constants of Ni and $Ni_{1-x}Pt_x$ alloys





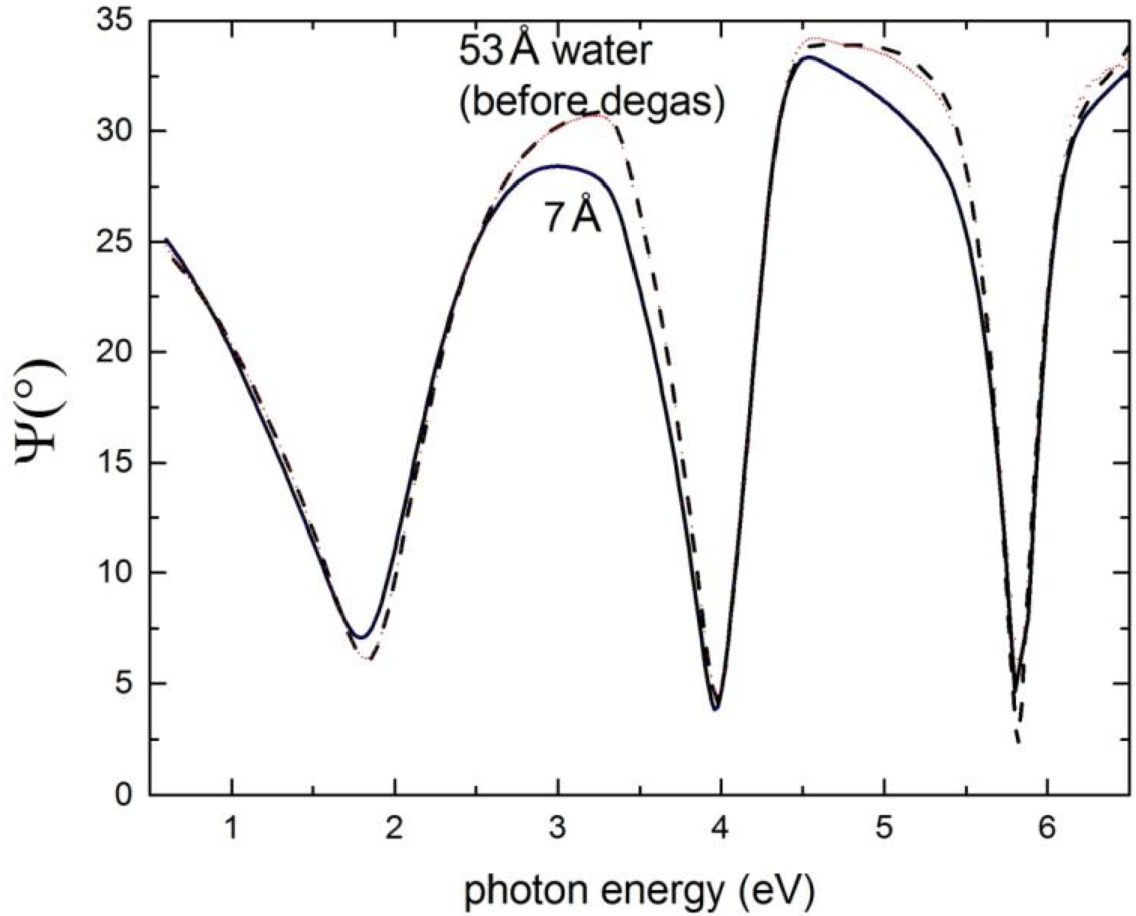
2	Ni-Pt alloy	100 Å
1	SiO_2	2000 Å
0	Si	



Pt 5d bands are broader than Ni 3d bands.

Thus, peaks in $Ni_{1-x}Pt_x$ alloys are broader than in pure Ni.

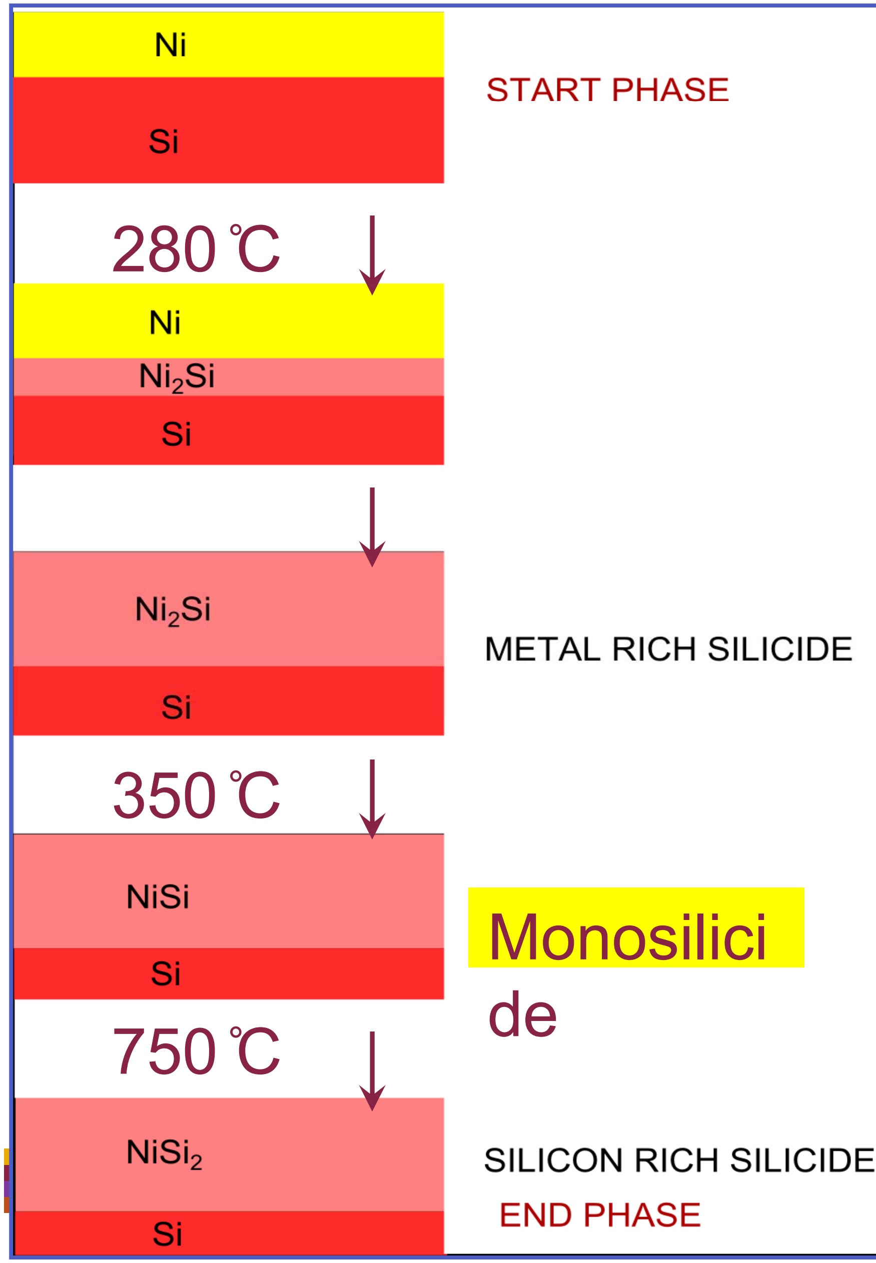
Water absorption metals could be a problem



- Ni-Pt alloy on thick thermal oxide.
- Keep in air for a year: **53 Å of water**
- Heat in UHV for an hour: 7 Å of water

Must de-gas wafer before ellipsometry measurement to remove atmospheric molecular contamination (water, solvents, etc).

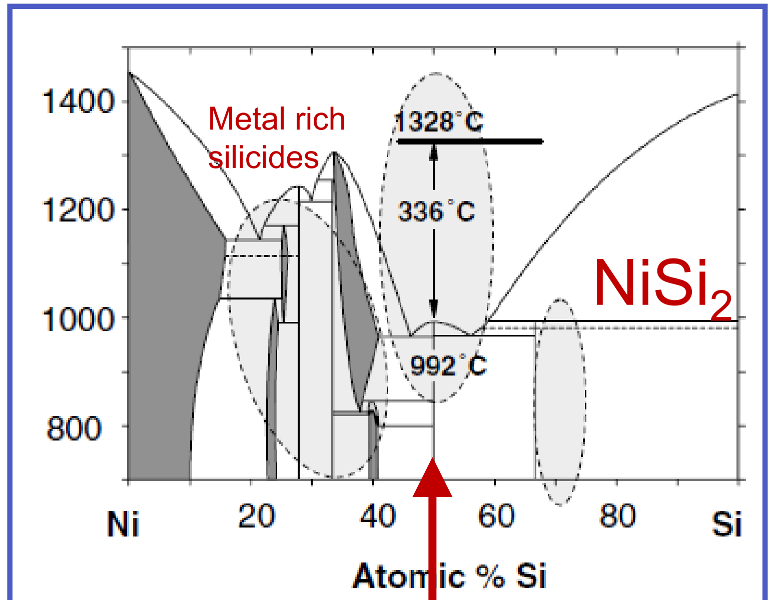
NiSi Formation



NiSi: Unstable at high temperatures

$NiSi_2$ formation

Agglomeration (thin films)



Effects of additive elements on the phase formation and morphological stability of nickel monosilicide films

C. Lavoie [a,b,*], C. Detavernier [c], C. Cabral Jr. [a], F.M. d'Heurle [a], A.J. Kellock [d], J. Jordan-Sweet [a], J.M.E. Harper [e]

Microelectronic Engineering **83,** 2042 (2006)

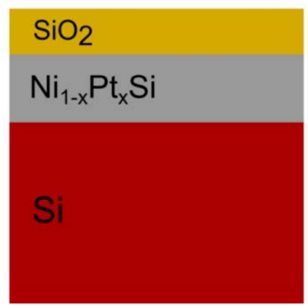
Ellipsometry of silicide films on Si

- $Ni_{1-x}Pt_x$
  (0%, 10%, 20%, 30% Pt)

- Annea 500˚C for 30 s

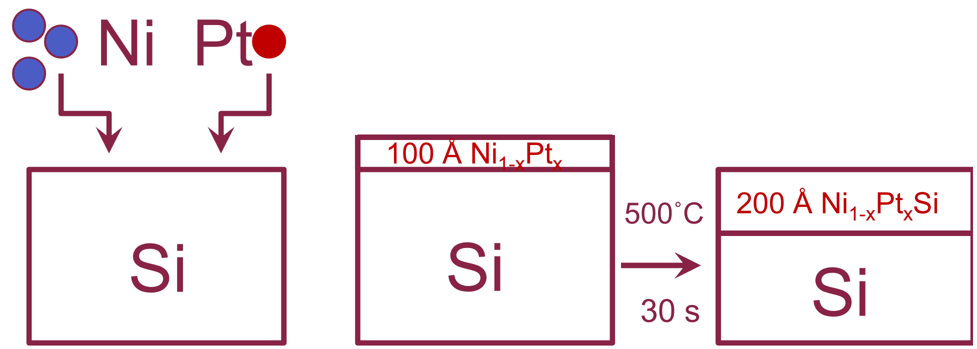
- Thickness of resulting silicide ≈
  2*metal thickness

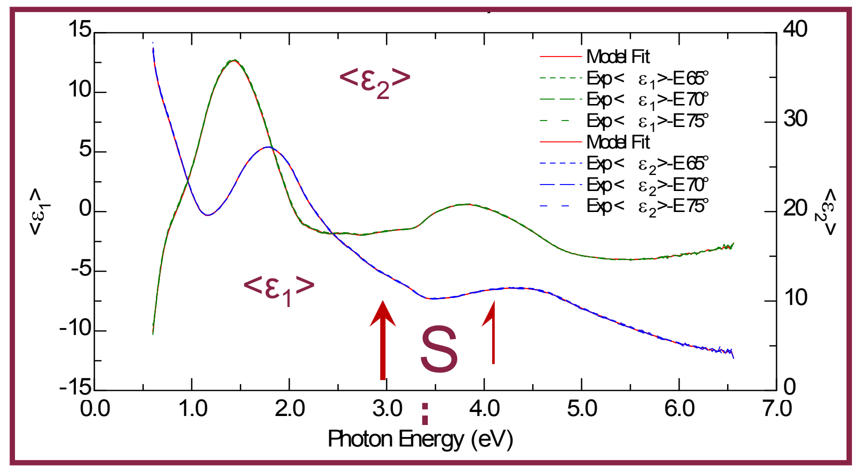
- SiO_2 is native oxide
  on NiSi.



- Three angles of incidence:
  65˚ to 75˚

- **Vary thickness of silicide to minimize Si substrate artifacts in pseudo-dielectric function.**

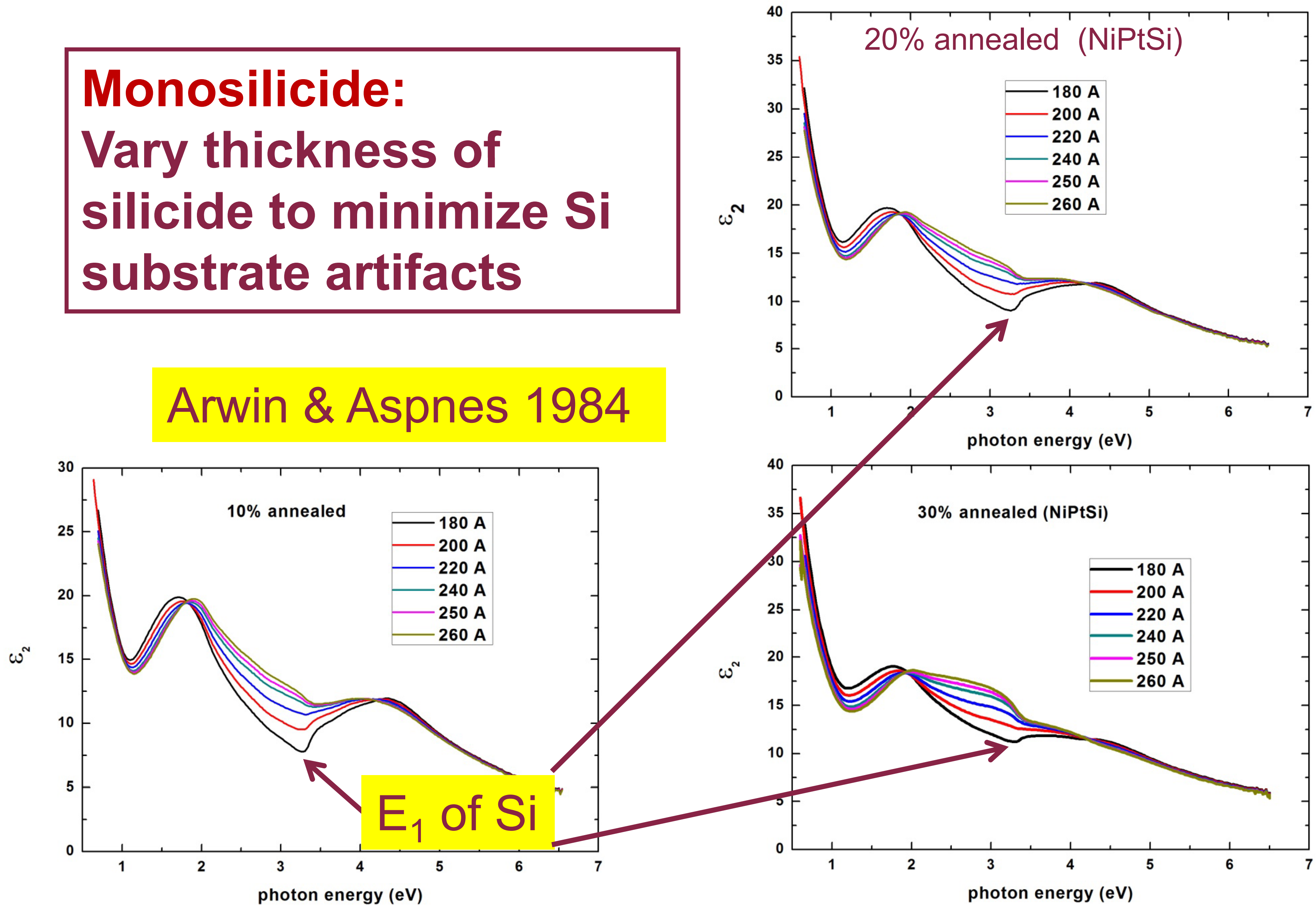




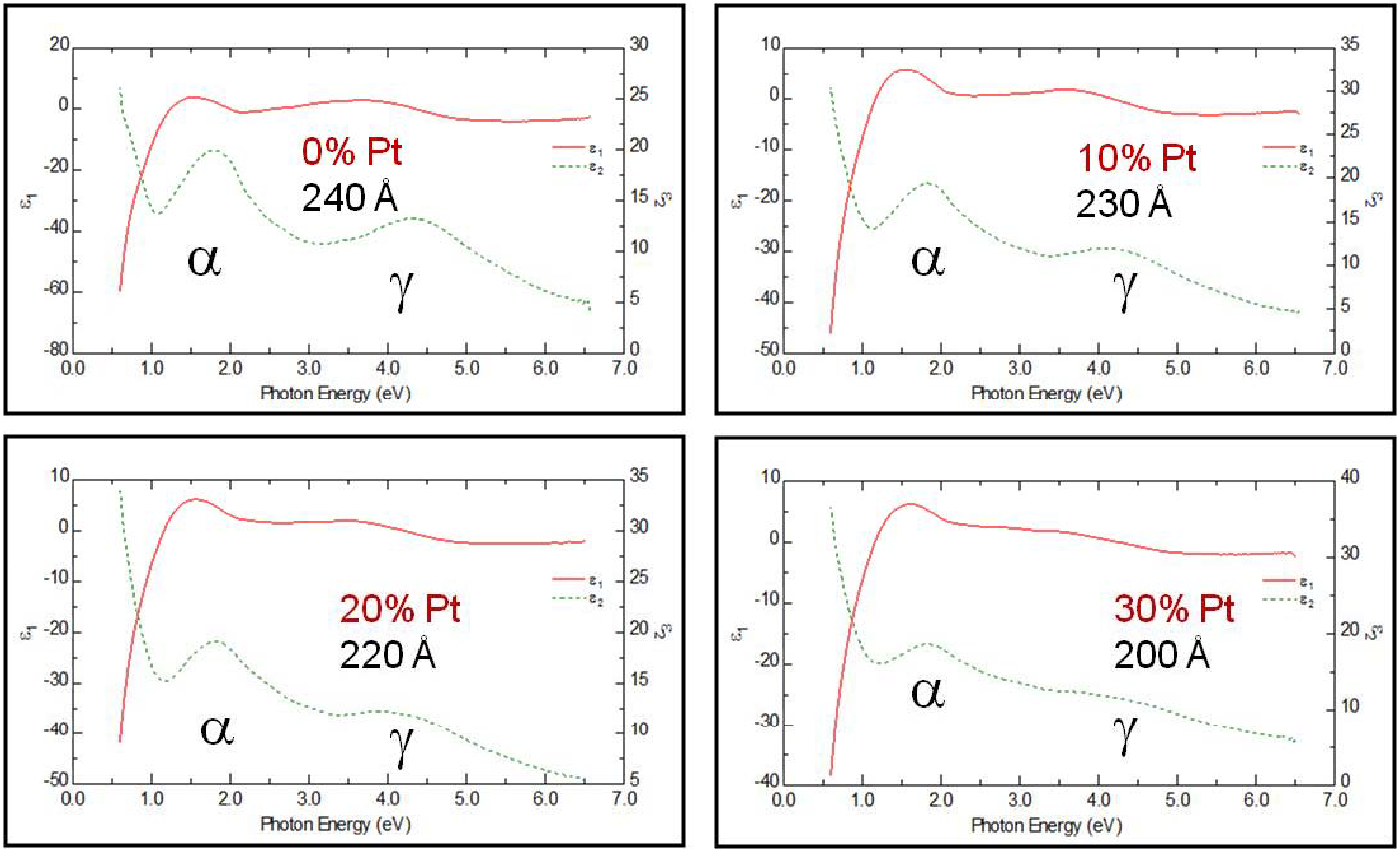
Pseudo dielectric function for mono Ni silicide (0% Pt)

Monosilicide:
Vary thickness of silicide to minimize Si substrate artifacts

Arwin & Aspnes 1984



Optical constants of $Ni_{1-x}Pt_xSi$



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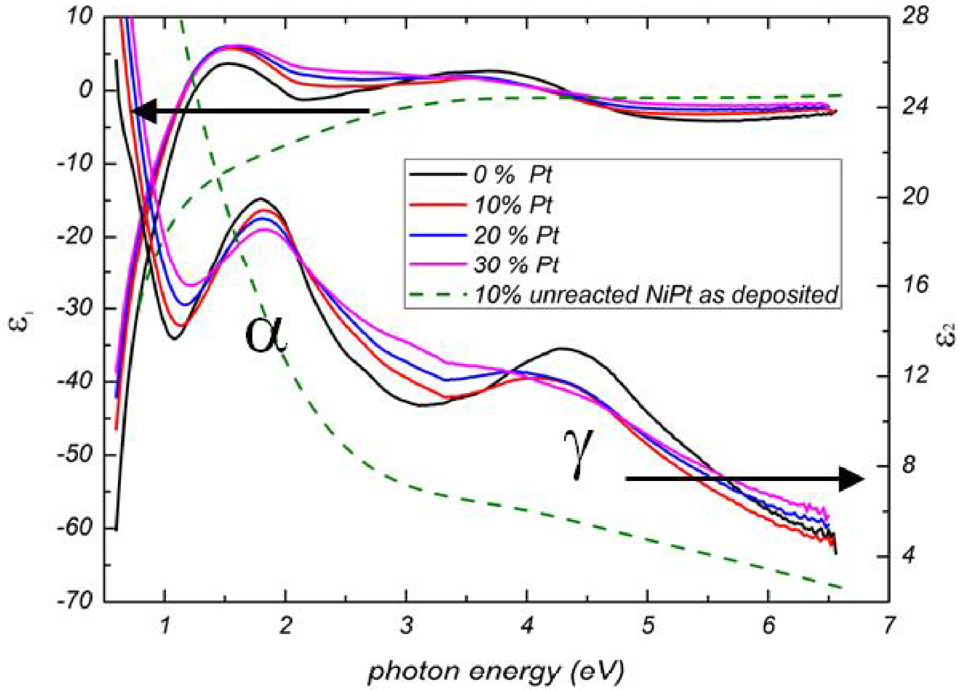
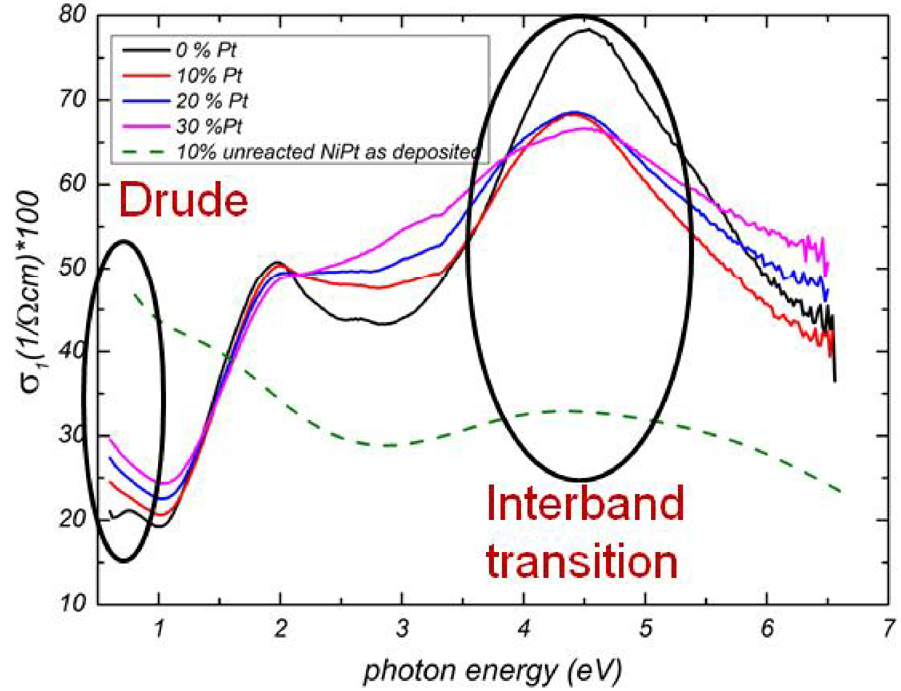
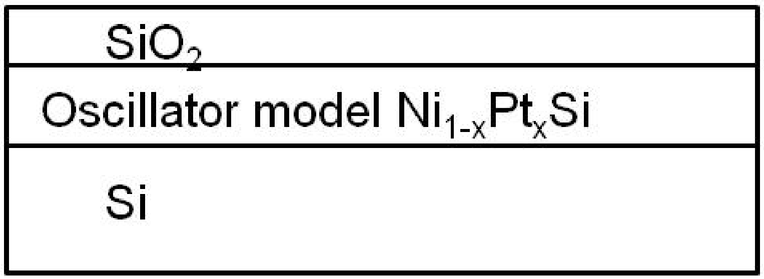
Optical constants of $Ni_{1-x}Pt_xSi$







Oscillator Model:

1 Drude (Free electrons + Intraband transitions)

5 Lorentz oscillators (Interband transitions)

http://ellipsometry.nmsu.edu

Broadening increases as Pt content gets larger.

Summary: Optical constants of $Ni_{1-x}Pt_x$ and $Ni_{1-x}Pt_xSi$

- Ellipsometry can measure metal and silicide film thicknesses. Some sensitivity to Pt content (broadening).
- Data posted at http://ellipsometry.nmsu.edu.
- Pt content broadens interband transitions in metal and silicides, because Pt-5d bands are broader than Ni-3d bands.
- NiPtSi optical conductivity exhibits metallic behavior due to the metallic content as well as interband transitions due to silicon-related electronic states.
- Free carrier absorption is stronger for unreacted metal than for silicide. However, interband transitions stronger for silicides.
- Interband transition peak gets broader with increasing Pt content in the silicide (can be explained in terms of NiPt DOS).

References

- All data (real and imaginary parts of the dielectric function versus photon energy) are posted on our web page: http://ellipsometry.nmsu.edu.
- We are available to measure flat films deposited by others using our high-accuracy Woollam VASE with autoretarder. Contact zollner@nmsu.edu.

- L. Abdallah, S. Zollner, C. Lavoie, A. Ozcan, and M. Raymond, *Compositional dependence of the optical conductivity of $Ni_{1-x}Pt_x$ alloys (0<x<0.25) determined by spectroscopic ellipsometry,* Thin Solid Films **571**, 484-489 (2014).
- L. Abdallah, T.M. Tawalbeh, I.V. Vasiliev, S. Zollner, C. Lavoie, A. Ozcan, and M. Raymond, *Optical conductivity of $Ni_{1-x}Pt_x$ alloys (0<x<0.25) from 0.76 to 6.6 eV*, AIP Advances **4**, 017102 (2014).
- Lina S. Abdallah, Stefan Zollner, Christian Lavoie, Ahmet S. Ozcan, and Mark Raymond, *Optical conductivity of $Ni_{1-x}Pt_xSi$ monosilicides (0<x<0.3) from spectroscopic ellipsometry*, J. Vac. Sci. Technol. B **32**, 051210 (2014).
- H. Bentmann, A.A. Demkov, R. Gregory, and S. Zollner, *Electronic and optical properties of PtSi thin films*, Phys. Rev. B **78**, 205302 (2008).