IR and AFM studies of diamonds for detector applications

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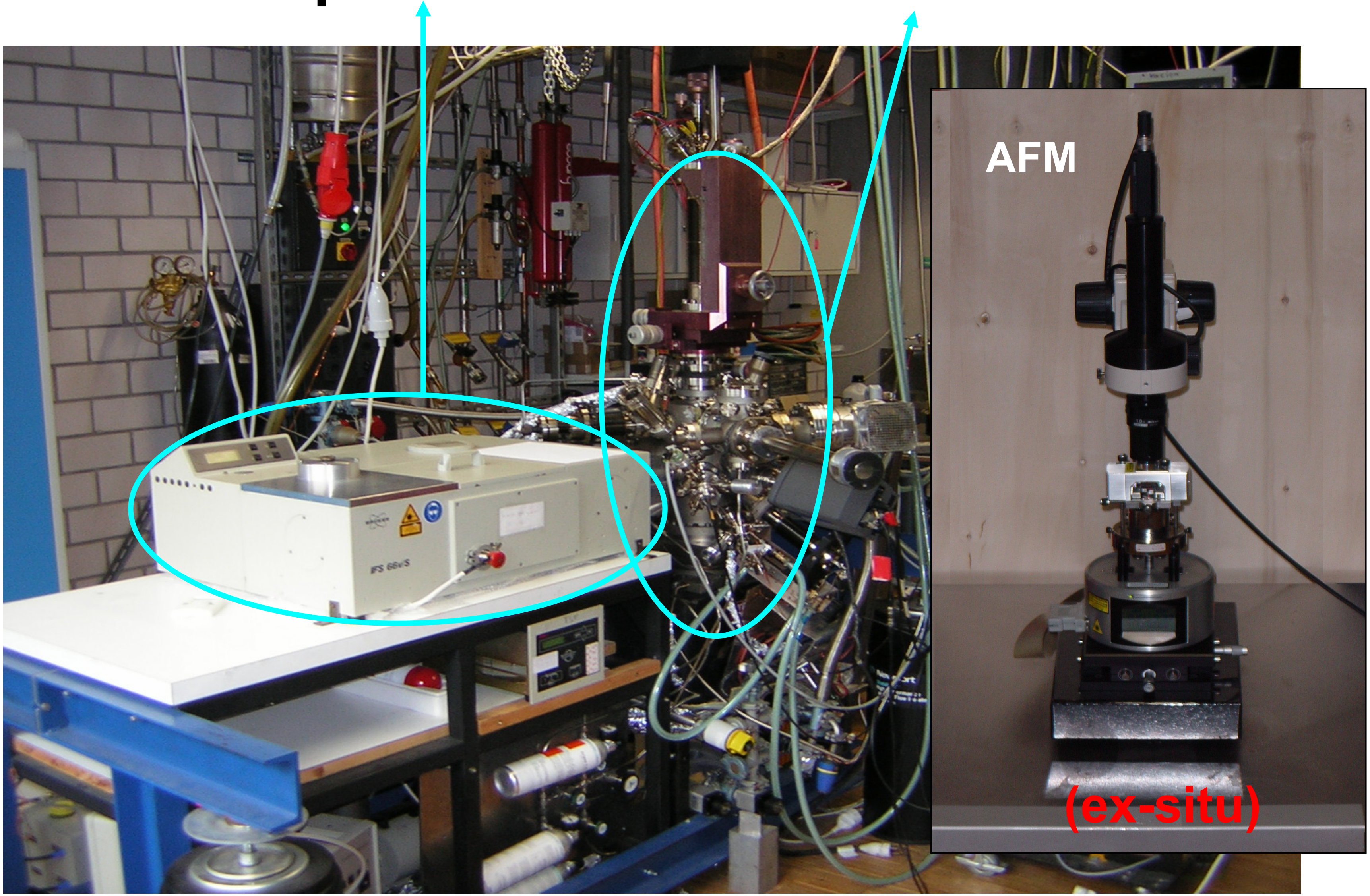
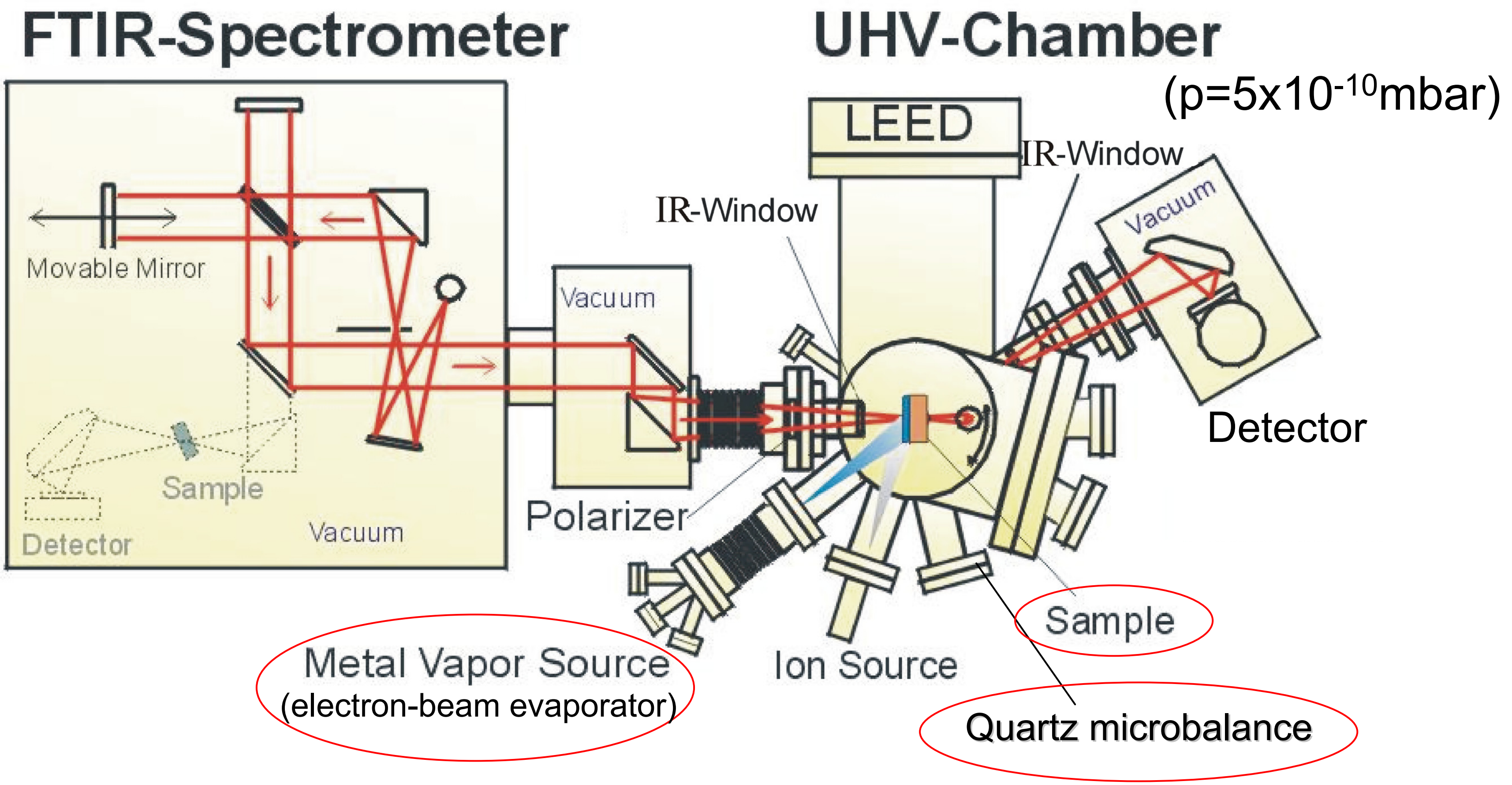
Content

- Experimental setup and what we measure
  - Ultra high vacuum (UHV) chamber
  - Atomic force microscopy (AFM)
  - IR-spectroscopy
  - Drude-model
- The diamond (100) surface
  - surface terminations and related electronic properties
  - Diamond-metal interfaces
  - AFM pictures of E6 diamonds
- First results: Cr on C(100)-(1x1):O
- Outlook

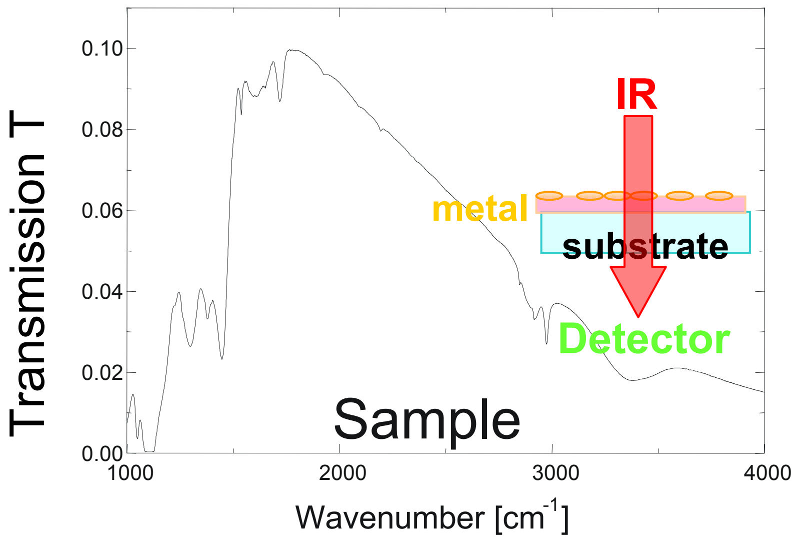
FTIR spectrometer and UHV chamber

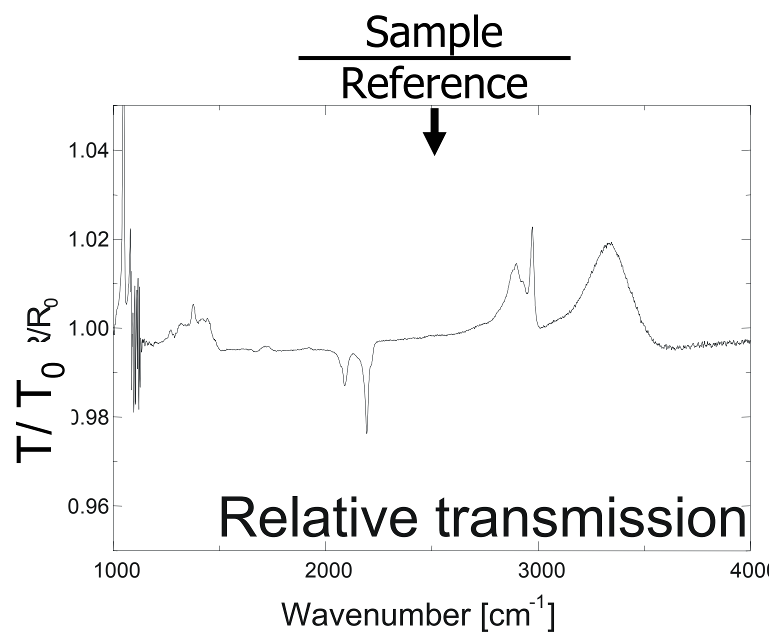


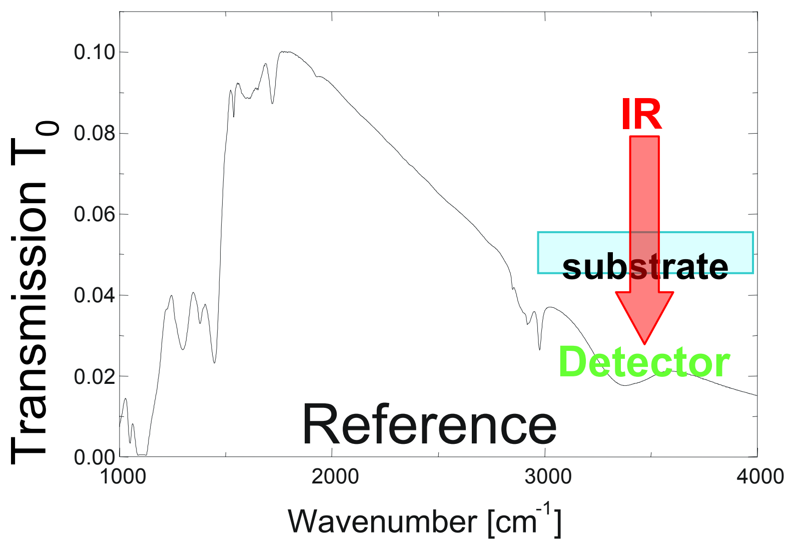


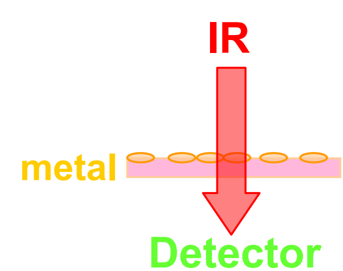
accessible sample temperatures: 40K to 1300K
surface preparation: heating, sputtering

Measurement of relative spectra









wavenumber: $\omega = \lambda^{-1}$

What we measure

- Mostly transmittance at normal incidence
- For ultrathin metal films $\left(d \ll \lambda / n_{\text{film}}\right)$

$$\frac{T_{\text{film/substrate}}}{T_{\text{substrate}}} \approx 1 - \frac{2 \cdot d \cdot \omega \cdot \operatorname{Im} \varepsilon_{\text{II film}}(\omega)}{c \cdot (1 + n_{\text{substrate}})},$$

$$\varepsilon_{\text{film}} - \varepsilon_{\infty} = \frac{\mathrm{i}\sigma(\omega)}{\omega \varepsilon_0}$$

In-plane conductivity measurement without electrical contacts

$$\varepsilon_1(\omega) = \varepsilon_{\infty} - \frac{\omega_p^2}{\omega^2 + \omega_\tau^2}$$

$$\varepsilon_2(\omega) = \frac{\omega_\tau \cdot \omega_p^2}{\omega^3 + \omega \cdot \omega_\tau^2}$$

$$\omega_p = \sqrt{\frac{ne^2}{\varepsilon_0 m_{\text{eff}}}}, \omega_\tau = \frac{1}{\tau}$$

Thin film corrections

$$\omega_\tau \rightarrow \omega_\tau(d) = \omega_\tau^{bulk} + \omega_\tau^{surf}(d)$$

due to scattering of electrons at the surface,

depends strongly on roughness

$$\omega_p \rightarrow \omega_p(d) = \beta(d) \cdot \omega_p^{bulk}$$

band bending at interfaces causes change of m_{eff} and

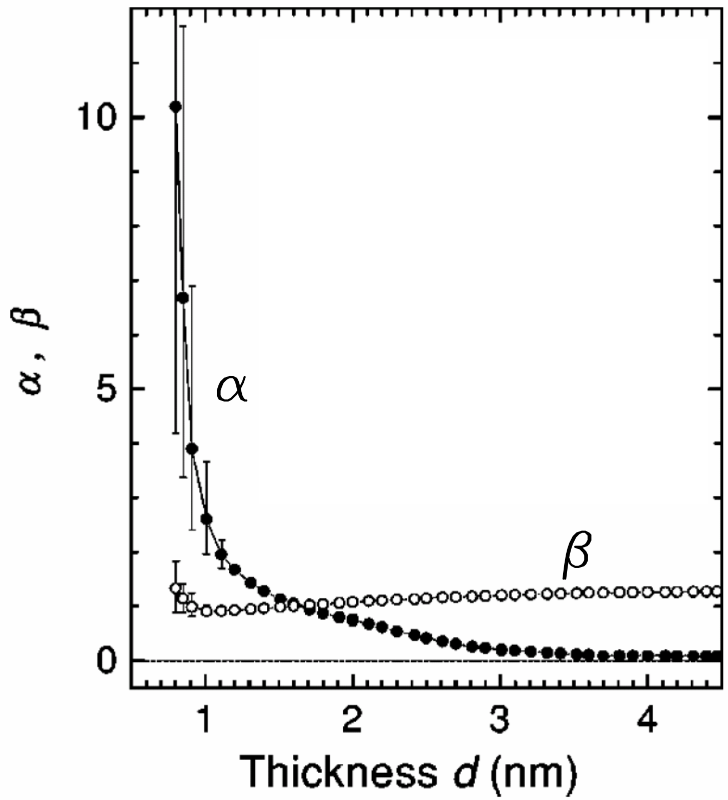
Schottky effect at metal - semiconductor contacts leads

to electron transfer which influences n

$$\varepsilon_1(\omega, d) = \varepsilon_\infty - \frac{\omega_p(d)^2}{\omega^2 + \omega_\tau(d)^2}$$

$$\varepsilon_2(\omega, d) = \frac{\omega_\tau(d) \cdot \omega_p(d)^2}{\omega^3 + \omega \cdot \omega_\tau(d)^2}$$

Example: Fe on MgO(001)



Fahsold et al., PRB 61, 14108

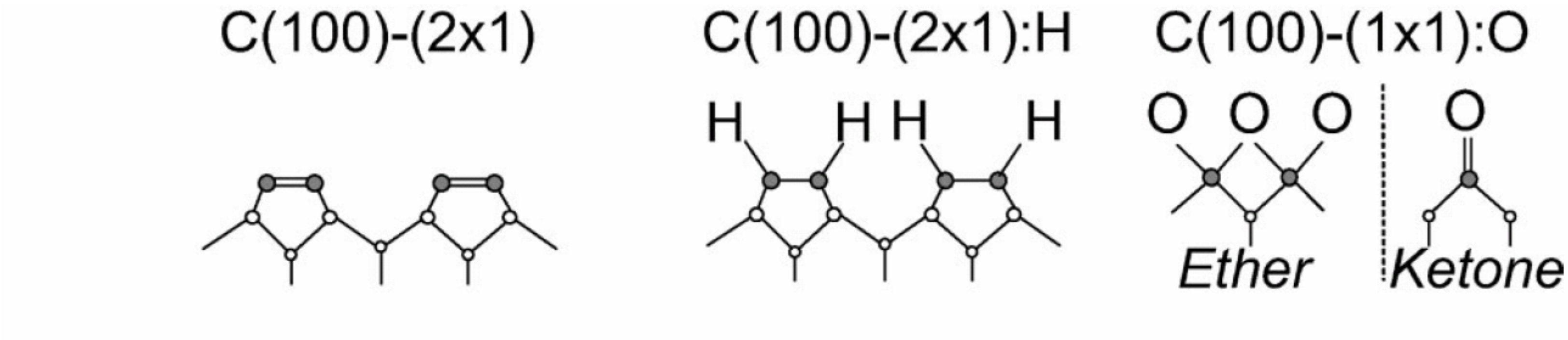
Parameters α (solid circles) and β (open circles) for a Fe-film on MgO.
α=0 and β=1 correspond to bulk values for the relaxation rate and the plasma frequency, respectively.
Below a thickness of ~0.8nm, the film cannot be described by a Drude-type dielectric function.

Thin film growth

Metal thin films can be trapped in many equlibrium conditions, depending on several preparation conditions, e. g.

- -evaporation rate
- -background pressure
- -substrate temperature
- -substrate structure
- -…

The diamond (100) surface

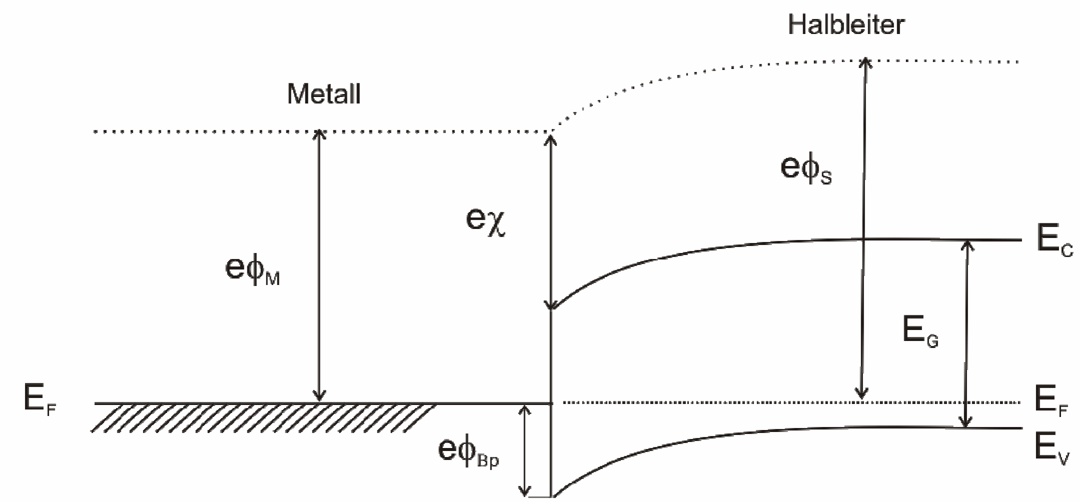


Maier et al., PRB 64, 165411 (2001)

Hydrogen terminated diamond exposed to air exhibits a high surface conductivity and is hence inapplicable for detector applications

Metal-diamond interface

p-Halbleiter



band bending at interface due to constant Fermi energy

barrier height for p-semiconductor
(if no Fermi level pinning occurs):

$$\Phi = E_{\mathrm{g}} + \chi - \Phi_{\mathrm{M}}$$

Electron affinitys of diamond surfaces

	χ[eV]
C(100)-(2x1)	0.5
C(100)-(1x1):O	1.7
C(100)-(2x1):H	1.3

Ways to control the barrier height

- evaporating carbide forming metals (Ti, Mo, Cr) and subsequent annealing (~600°C)
- removing oxidation in UHV before metallization

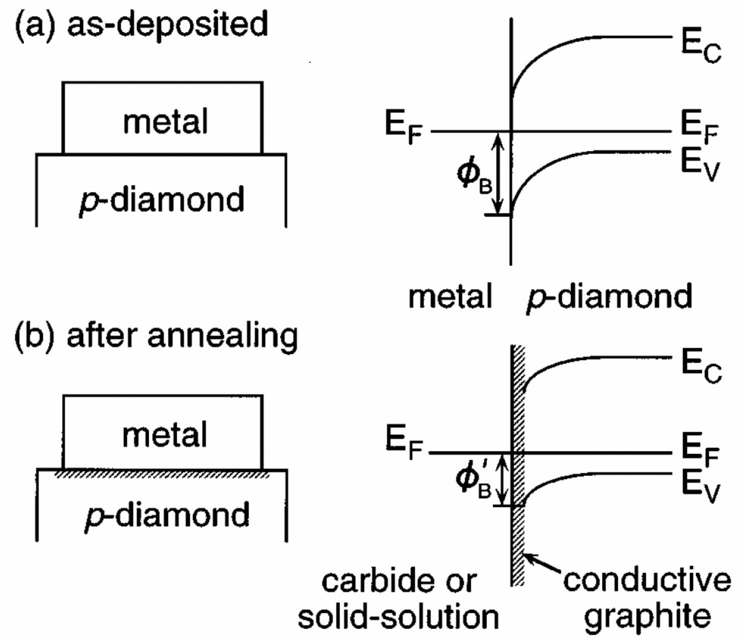


FIG. 7. Interfacial band diagrams at the *p*-diamond/metal interface: (a) as-deposited metal on diamond, (b) conductive graphite layer induced by carbide formation.

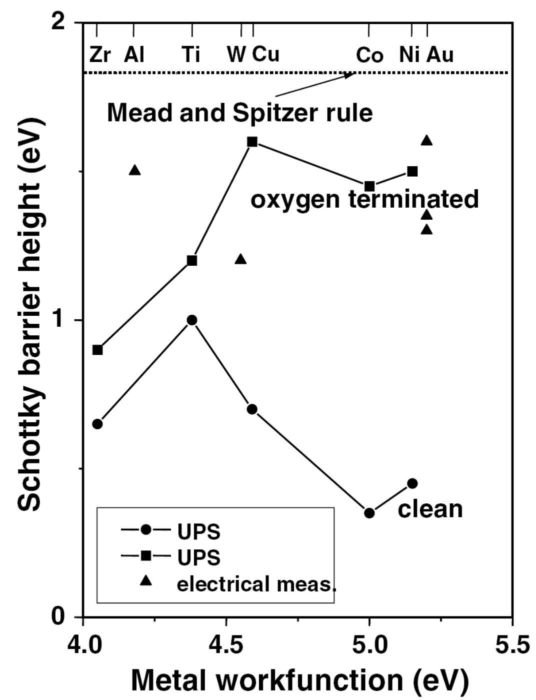


Figure 1. Comparison of the measured Schottky barrier heights on clean and oxygen-terminated surfaces.

Yokoba, J. Appl. Phys. 81, 6815 (1997)   Werner, Semicond. Sci. Technol. 18, 41 (2003)

Oxidation of diamond surface

•Wet-chemical treatment with H_2SO_4 and KNO_3 at 240°C to oxidize the surface and remove conductive graphite phases
•alternatively, the surface can be treated by oxygen-plasma
•Examination of oxidation quality with IR-spectroscopy? (it is known that acid treatment does leave some residual hydrogen on the surface)

Diffuse reflectance infrared spectroscopy of diamond crystallites
stretching mode of a carbonyl group at 1731cm^{-1}

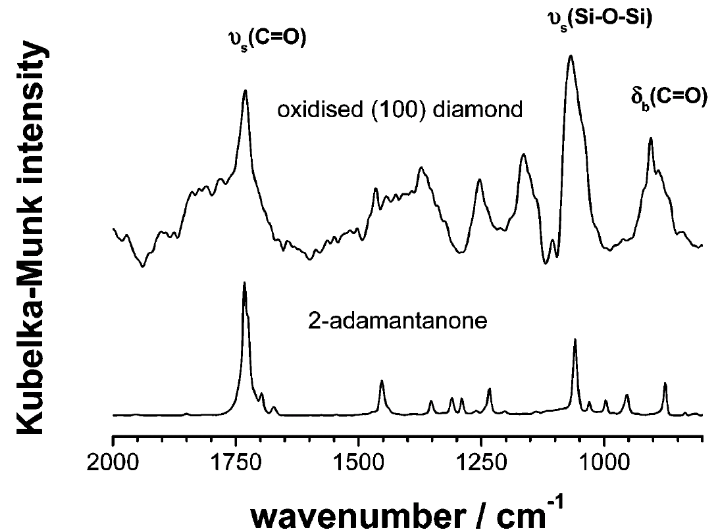
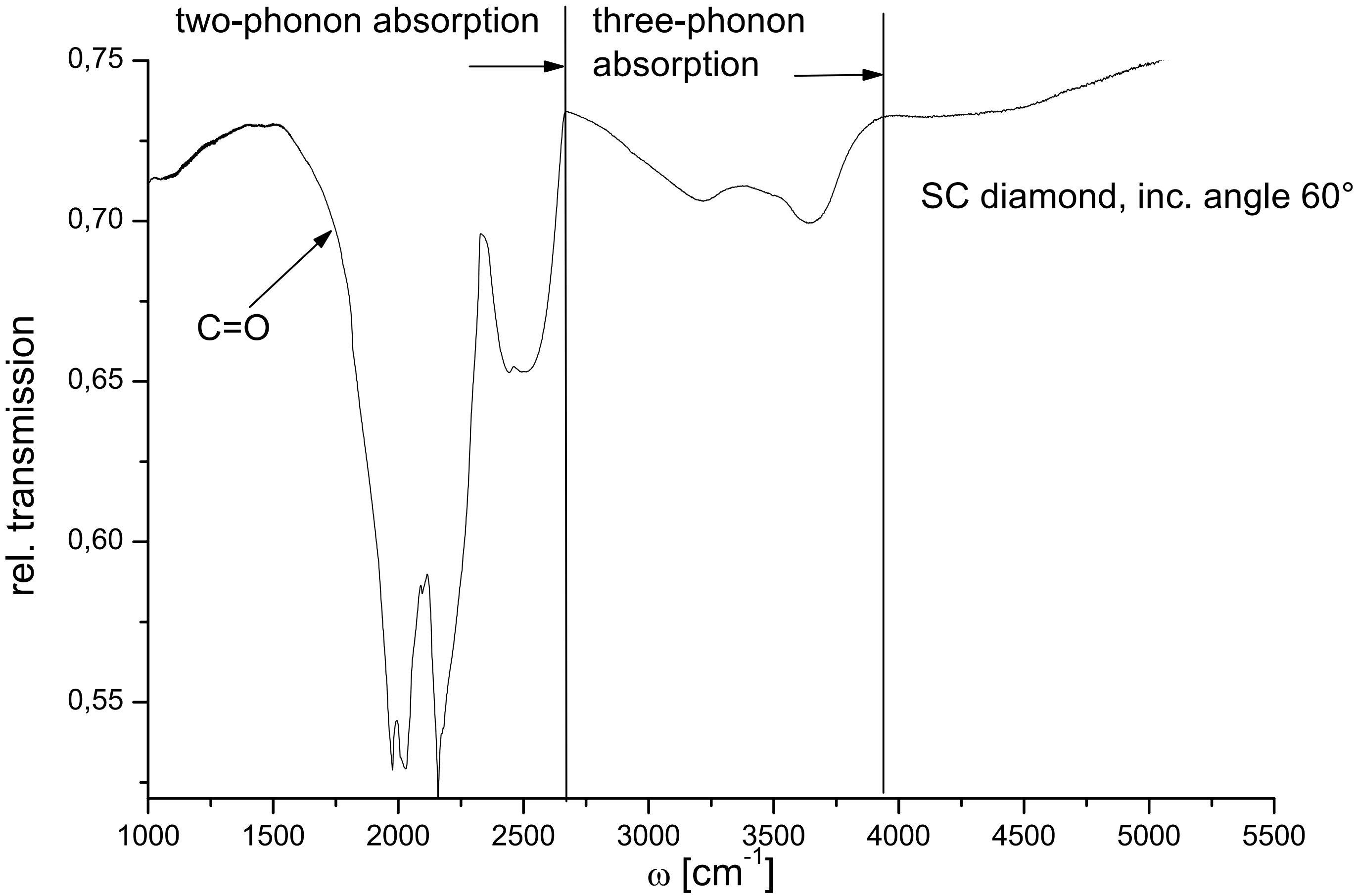


Figure 1. DRIFT spectra of (100) diamond oxidized at 700 °C, for 10 min in 150 Torr O_2, and powdered 2-adamantanone − the vibrational spectrum of 2-adamantanone has been assigned[21] previously.

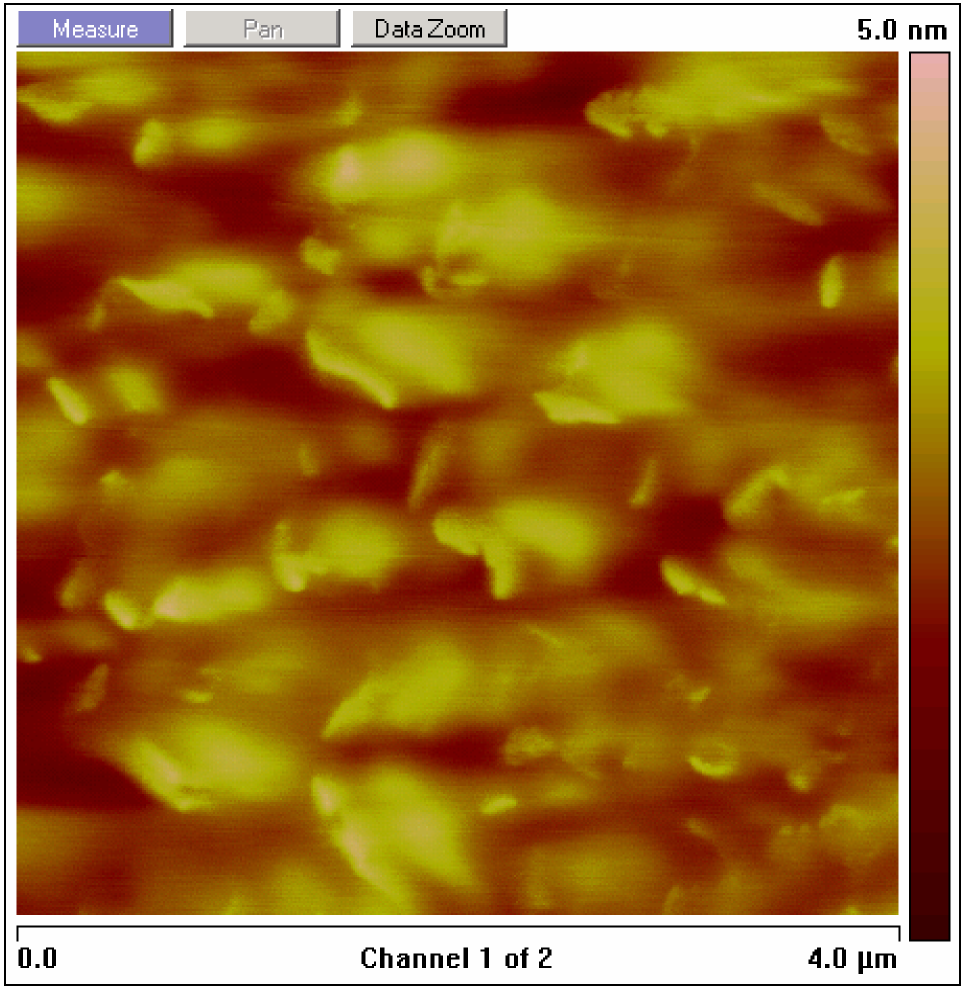
J. Am. Chem. Soc. 125, 6600 (2003)

IR-transmission spectrum



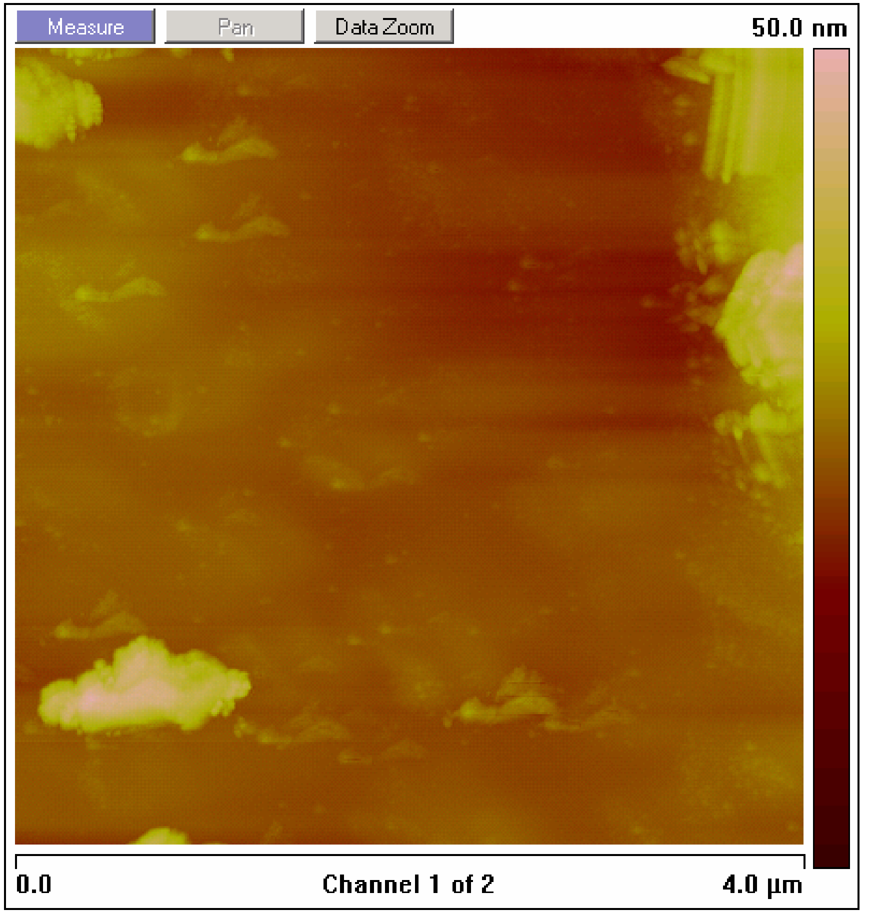
insufficient surface sensitivity in transmission geometry

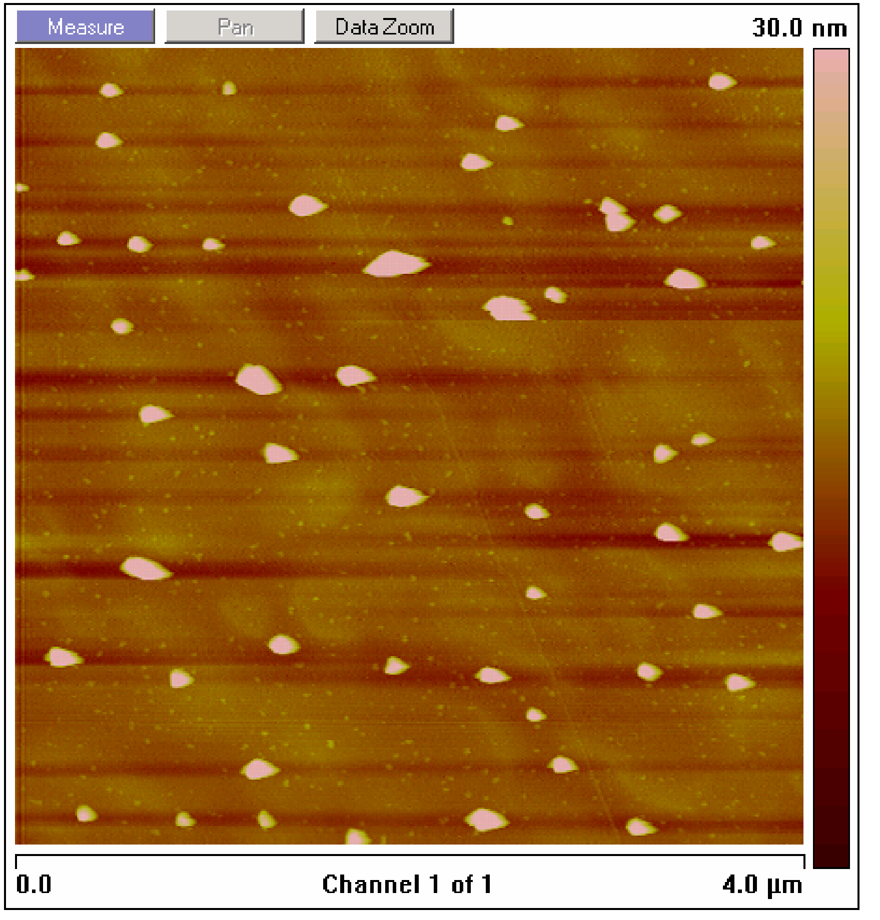
AFM pictures of an E6 diamond



rather smooth, roughness of a few nanometers

but in other areas…





Different morphology for different places on the diamond.
Influence of wet-chemical treatment?

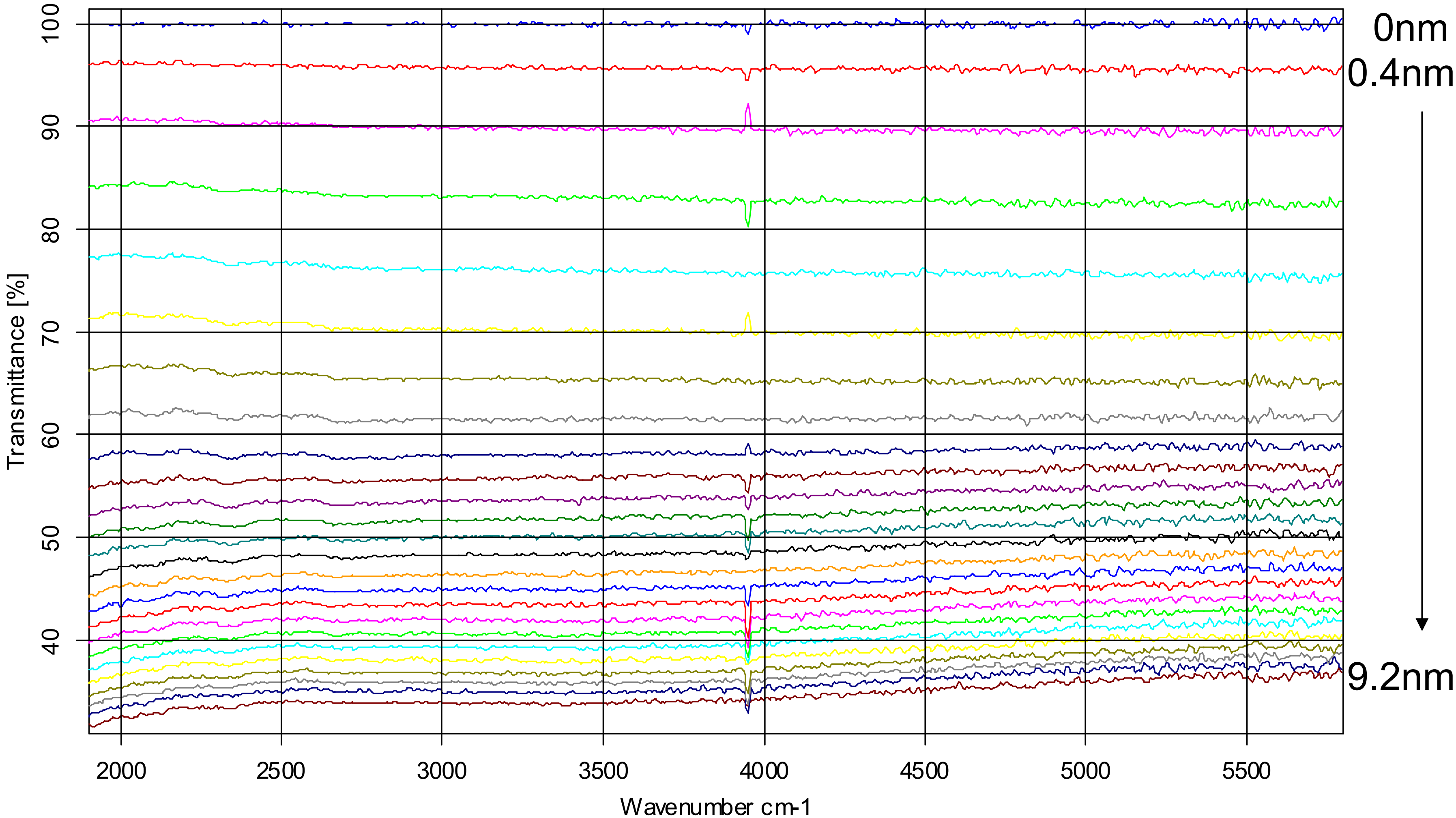
In order to achieve reliable information about metal film growth, a well defined substrate is needed!

Experimental procedure for Cr-film growth

- oxidizing with H_2SO_4 and KNO_3 at 240°C
- transferring into UHV and heating to 400°C in order to clean surface
- evaporating Cr with a rate of ~900sec/nm, substrate at room temperature

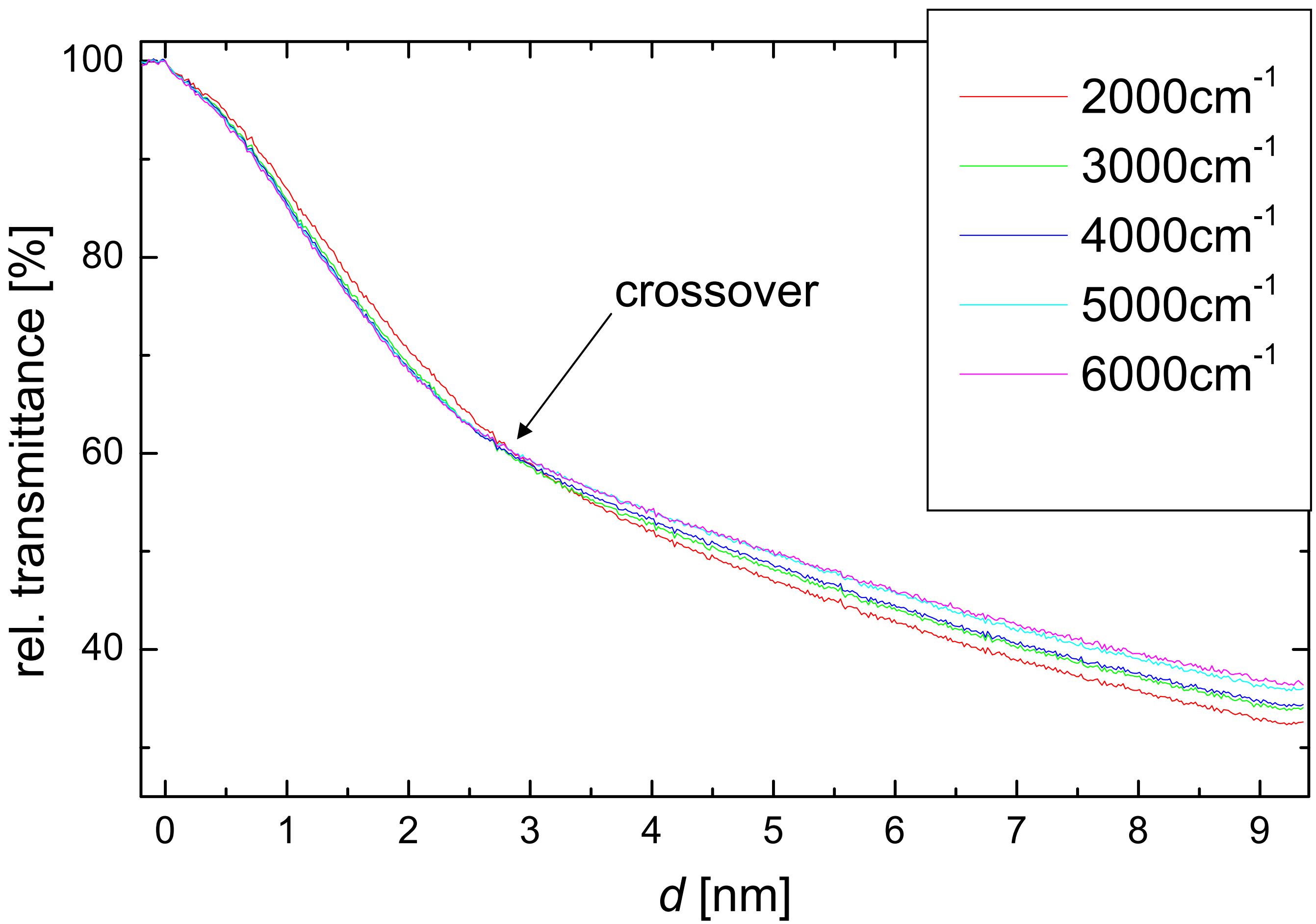
LEED-pattern of C(100)-(1x1):O

First results: Cr on C(100)-(1x1):O

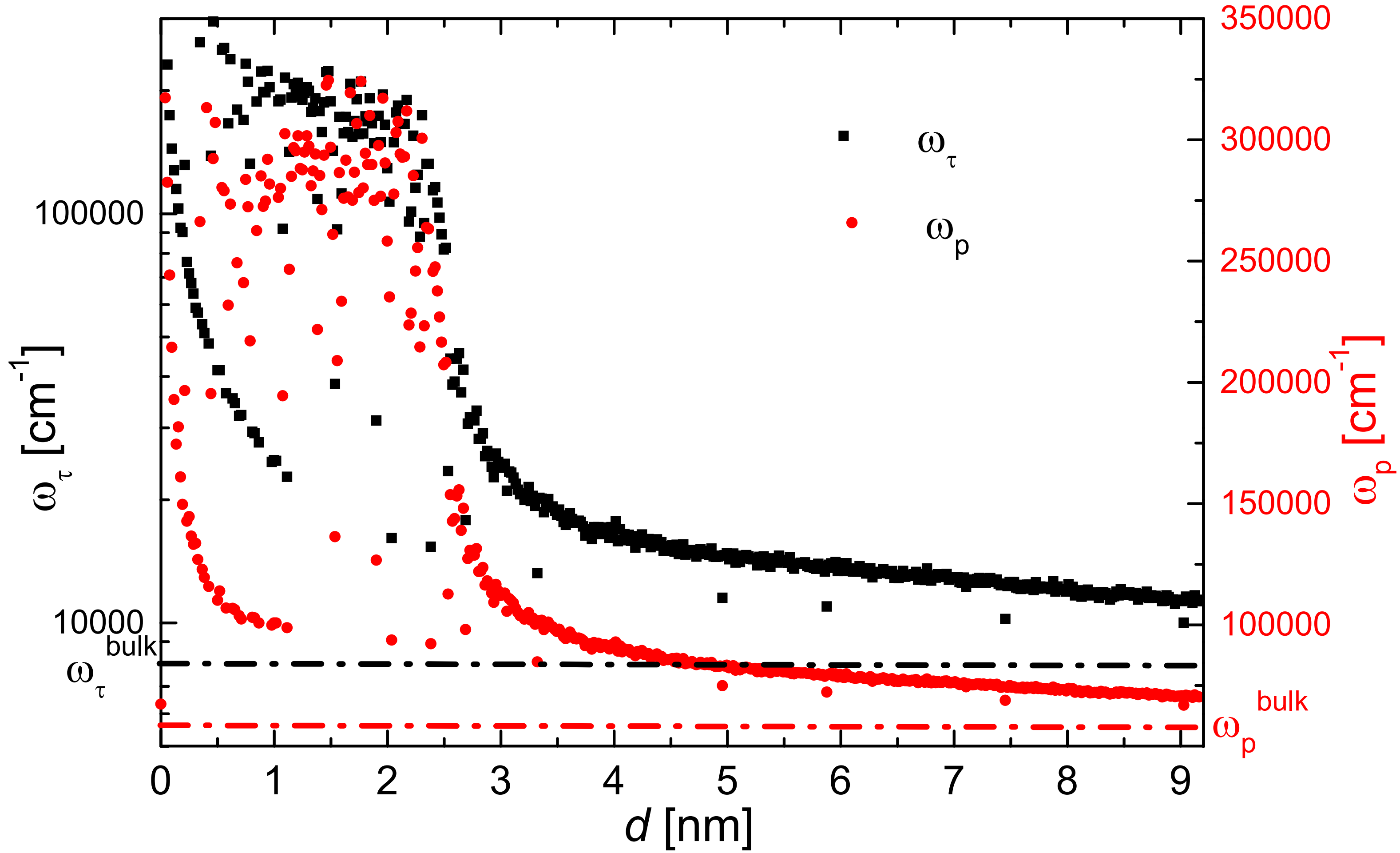


IR-spectra measured during Cr-evaporation

Development of transmission at different frequencies

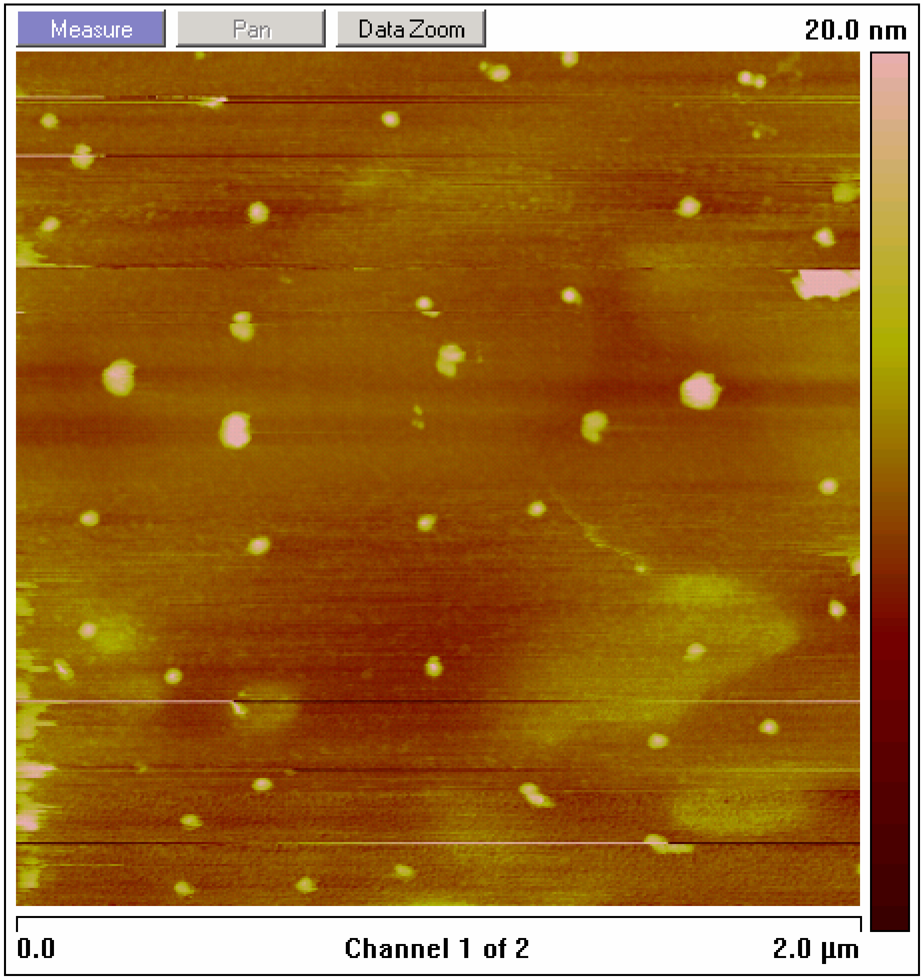


Effective Drude parameters

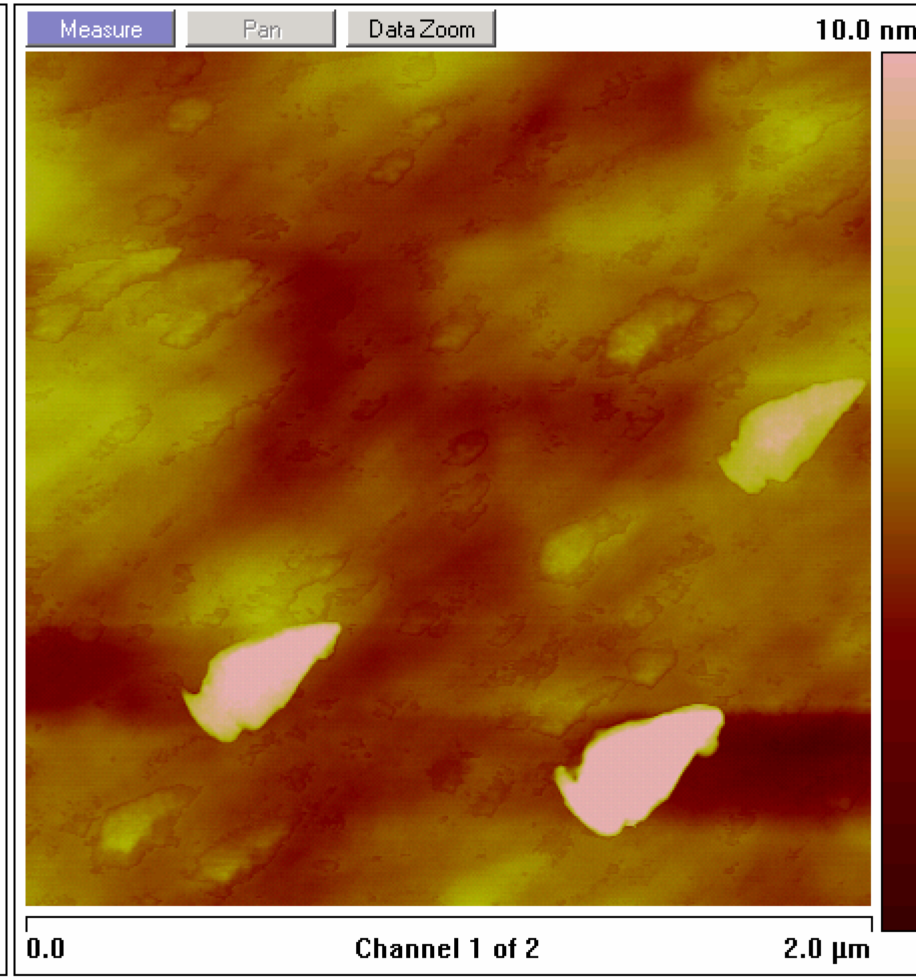


•spectra fitted from 3000 to 5000cm^{-1}, constant ω_p and ω_τ for bulk Cr assumed
•from 2.5 nm on, the IR-spectra of the film can be described by a Drude-type dielectric function

AFM measurements



substrate nearby



Cr-Film

Outlook

- influence of diamond morphology on film growth has to be studied
- comparison of wet-chemical and oxygen-plasma oxidation
- investigation of chromium-carbide formation

Thanks

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