Optical microscopy – conventional (visible) light microscopy	
Detection signal	Optical absorption (transmission), Reflection – in combination with spectrometer also spectral resolution
Sample prerequisites	Optical transparent, sufficient reflection (contrast !?)
Advantages	Routine instruments, different contrast modes (absorptions, bright/dark field, phase contrast etc.)
Disadvantages	Resolution is diffraction limited (λ = 400 – 800 nm) In general $\Delta x = \frac{\lambda}{2 \cdot NA}$ (NA = numerical aperture ↔ acceptance angle)
Achievable resolution	See above
Typical applications	Routine applications – quick specimen inspection

Optical microscopy – confocal microscopy (Laser scanning confocal microscopy - CLSM/ LSCM)	
Detection signal	Usually fluorescence light of labelled specimens
Sample prerequisites	Sufficient optical activity (achieved through fluorescence labels)
Advantages	3D imaging possible by focus series and subsequent image reconstruction
Disadvantages	High investment costs, in particular in combination with multi-colour laser system
Achievable resolution	Similar to light microscopy – imaging of single quantum objects (fluorescence)
Typical applications	Single molecule spectroscopy (diluted fluorescent molecules)

Optical microscopy – Raman-microscopy	
Detection signal	VLM combined with high spectral detection (Raman-Effect → very high chemical sensitivity)
Sample prerequisites	moderate topography variations, optical response
Advantages	highest spectroscopic resolution (optical excitation) combined with very good spatial resolition
Disadvantages	High Investment cost (for scanning instruments)
Achievable resolution	Few 10 nanometers (SNOM)
Typical applications	Surface chemistry at single (diluted) objects, carbonaceous materials, CNT, graphene

Scanning Probe Microscopy – Scanning tunneling microscopy (STM)	
Detection signal	Tunneling current (pA – nA) between conducting (metallic) tip and sufficiently conducting specimen; variable tunneling voltage Exponential distance dependence of tunneling current
Sample prerequisites	Conductivity, moderate sample corrugation, moderate surface corrugation
Advantages	very high lateral resolution → submolecular resolution tunneling spectroscopy → local electron spectroscopy (I-V-Spectroscopy) selected cases: local vibrational spectroscopy applicable in different surroundings (ambient, from UHV to electrolytes)
Disadvantages	Requirement for sufficiently conducting specimens NB: STM detects variations in the local density-of-states (DOS), not atoms ! no chemical sensitivity (in the sense of elemental analysis)
Achievable resolution	In the Angström-regime („subatomic“) – exact positioning of the tip by piezo elements
Typical applications	Surface morphology, surface structure, adsorbate (super)structures organic films, large molecules manipulation of adsorbate molecules

NB: scanning probe microscopies have limited scan regions because of piezoscanner

Scanning Probe Microscopy – Scanning Force Microscopy (SFM/AFM = atomic force microscopy)	
Detection signal	Deflection of a cantilever (with very fine tip) due to various local interactions (attractive, repulsive, vertical and lateral forces) Signal originates mainly from the surface
Sample prerequisites	Moderate surface corrugation, from conducting to insulating substrates
Advantages	contact- / non-contact mode large variety of samples (compared to STM) high lateral and vertical resolution different interactions → many local properties accessible (e.g., magnetism) local elasticity (force spectroscopy, friction)
Disadvantages	Can difficult to employ in UHV demanding tip preparation (costs !)
Achievable resolution	In ideal cases atomic resolution, mostly in the nanometer regime
Typical applications	surface morphology, biology/life sciences, force spectroscopy (force-distance measurements)

Scanning Probe Microscopy – Scanning near-field optical microscopy (SNOM/NSOM)	
Detection signal	Light absorption & emission ↔ fluorescence (not suitable for IR regime due to limitations in fiber optics) Measures the optical response from the surface or dye molecules
Sample prerequisites	surface corrugation must be small optical activity, usually fluorescence labels (→ biology)
Advantages	single molecule spectroscopy chemical Information nanolithography is possible
Disadvantages	tip preparation very demanding and time-consuming tip determines lateral resolution (prepared pinhole)
Achievable resolution	< 50 nm, however not as good as AFM/STM
Typical applications	biological specimen, optically active media

Electron microscopy – Scanning electron microscopy (SEM)	
Detection signal	Secondary processes (Auger electrons, x-ray fluorescence, sample current, back scattered electrons) Electron energy: > 1 keV (higher energies improve spatial resolution)
Sample prerequisites	Conducting samples, vacuum compatible (low vapour pressure)
Advantages	x-ray fluorescence → information about element distribution, stoichiometry, i.e. quantitative fast data collection, large variation in the „area of interest“ (easily zoom-in & zoom out) complements VLM as a routine microscopic technique surface sensitivity, topography (some limitations) simple handling (see students lab course)
Disadvantages	vacuum required (< 10^{-6} mbar) sample damage by high energy electrons conducting samples required to prevent charging (eventually deposition of metals or carbon)
Achievable resolution	3 – 20 nanometers
Typical applications	any kind of solid/condensed samples (vacuum compatible) that offer morphology and/or elemental contrast

Electron microscopy – Transmission electron microscopy (TEM)	
Detection signal	transmitted electron intensity, access to scattered/diffracted electrons in addition: electron diffraction to combine structural information with image information
Sample prerequisites	only very thin specimens (thickness < 100 nm) – may require intense sample preparation (“microtoming”) vacuum required
Advantages	Different contrast mechanisms (bright vs. dark field) Interference contrast Information in reciprocal and real space accessible Highest achievable resolution (for thin bulk samples) = volume information Tomography (in particular biological specimens) chemical information, if energy filtering → EELS (electron energy loss spectroscopy), basics like in NEXAFS
Disadvantages	Many samples requires specific preparation to enhance contrast, e.g., stainig of bio samples (selectives incorporation of heavy metal salts) vacuum required sapmle preparation may lead to artefacts Beam damage, in particular soft matter samples (improved in cryo microscopy at about 4 K) High costs (> 1 Mio. €), including aberration correction 1.5 – 2 Mio USD
Achievable resolution	< 1 Å
Typical applications	All types of condensed matter, material science, biological specimems

Electron microscopy – Photo electron emission microscopy (UV-/soft x-ray excitation – PEEM/XPEEM)	
Detection signal	Secondary electron emission, surface sensitive
Sample prerequisites	Sufficiently conducting substrates, moderate corrugation, specimen diameter few millimeters
Advantages	Simple to operate with commercial instrumentation (NB: XPEEM requires access to synchrotron radiation) Different contrast mechanisms (work function, NEXAFS = high absorption cross section, non-resonant excitation low cross section, comp. XPS) In-situ detection possible (growth, adsorption, catalytic reactions)
Disadvantages	Ultrahigh vacuum (UHV) required ! (otherwise potential surface contamination) Only surface sensitive (due to limited inelastic mean free path of secondary electrons) High resolution requires high photon flux densities = potential specimen damage
Achievable resolution	< 40 nm (x-ray excitation), < 20 nm (UV excitation) – reason: different photon flux densities, improved contrast for UV-PEEM For aberration-corrected instruments: few nm
Typical applications	Surface spectroscopy (adsorbates, nanostructures), surface microscopy In-situ processes at surfaces

NB: radiation damage mostly due to secondary electrons with energies > 30 eV

Electron diffraction (ED, LEED, RHEED)	
Detection signal	Scattered or diffracted electron beam
Sample prerequisites	Single crystal (in back scattering geometry) → LEED Thin samples for ED in TEM („forward scattering“)
Advantages	Bond distances (TEM), surface sensitive (LEED),simple setup (LEED) → routine analytics
Disadvantages	UHV Multiple scattering events (difficult simulation) - XRD: single scattering event
Achievable resolution	Bond length: 0,05 nm – in combination with TEM/LEEM: 3 – 5 nm in microscopy mode
Typical applications	Surface structure, adsorbates (LEED, LEEM) – microcrystalline materials (TEM)

What do we learn from the super structure matrix ?

Electron microscopy – Low-energy electron microscopy (LEEM)	
Detection signal	Spatially resolved reflection of low-energy electrons (diffraction, reflection) Imaging in electron microscopy column
Sample prerequisites	(partially) crystalline surfaces, rest like PEEM
Advantages	Combines high spatial resolution with structural information (diffraction) Different contrast mechanisms (bright field, dark field), mirror microscopy → surface potential (work function inhomogeneities) directly combined with PEEM
Disadvantages	UHV required Instrumentation cost (ca 1 Mio. €)
Achievable resolution	about 5 nm (aberration corrected:< 3 nm demonstrated)
Typical applications	surfaces, surface structures, adsorbate structures, in-situ growth

X-ray probes – x-ray diffraction (XRD)	
Detection signal	Diffracted x-rays into distinct direction
Sample prerequisites	Structural order on short length scales
Advantages	Exact determination of bond distances, atom-/molecule distances Different sample geometries (Laue, Debye-Scherrer, grazing-incidence diffraction (similar to RHEED) Variable sample surroundings (e.g. crystals under extremely high pressures)
Disadvantages	Some modes are only available with synchrotron radiation (however, there are many synchrotron sources available for structure analysis) Differences in electron density improves contrast and thus quantitative analysis
Achievable resolution	No direct imaging,however structural information on length scalesdown to 0,01 Å
Typical applications	All crystalline materials (with short- and long-range order) Debye-Scherrer → powder samples, Laue → single crystals

x-ray probes – x-ray microscopy	
Detection signal	Transmitted intensitiy <-> Lambert-Beer (absorption of x-rays, quantitative), phase contrast, or x-ray fluorescence (quantitative)
Sample prerequisites	Sample thickness (for transmission, depends on photon energy)
Advantages	contrast: x-ray absorption (NEXAFS), spectroscopic information about electronic strcture phase contrast (for higher photon energies, typically > 10 keV) magnetic contrast (XMCD, XLMD) tomography (3D-imaging) different sample surroundings (UHV - liquids)
Disadvantages	Expensive and demanding optics Synchrotron radiation advantageous Sample thickness (depending on photon energy/penetration length)
Achievable resolution	routinely 40 nm (soft x-rays), 80 - 100 nm (hard x-rays, in addition structural information from XRD)
Typical applications	All materials

x-ray probes – small-angle scattering (SAXS)	
Detection signal	scattering of x-rays using very small scattering angles
Sample prerequisites	Sufficient transmission
Advantages	Ensemble averaging, no microscopic information on individual objects Can be combined with local structural information (WAXS) Information about specimen shape (anisotropy)
Disadvantages	Data simulation important for data interpretation
Achievable resolution	few nm – several µm combination with structural information (bond length)
Typical applications	microcrystalline materials up tot he mesoscopic length scales block copolymers, biological samples

Ion based microscopies (He ion microscopy)	
Detection signal	
Sample prerequisites	
Advantages	
Disadvantages	
Achievable resolution	
Typical applications	

Ion –based microscopy – Atom probe tomography	
Detection signal	
Sample prerequisites	
Advantages	
Disadvantages	
Achievable resolution	
Typical applications	