Oral exam questions for Application of Neural Microsystems 2019

Lecture 1 (Introduction)

1. List examples of commercially available neuroprosthetics and their applications.
2. What are the spatial dimensions of neuronal structures and what is temporal scale of electric and chemical communication in the extracellular space?
3. List stimulation methods used to interact with neurons.
4. Explain what is MEMS and how is this field influenced by the progress in the semiconductor industry.
5. Explain why physical phenomena are different in the microscale.
6. What is the advantage of MEMS based neural probes?

Lecture 2 (Technology)

1. Explain CMOS technology briefly.
2. List basic semiconductor processes that are used fabricate silicon chips.
3. Why is the clean environment crucial in the semiconductor industry?
4. Describe the process flow for photolitography.
5. Describe the „lift-off" process.
6. Compare CVD and PVD processes in terms of process temperature, step coverage and film purity.
7. Describe the processes of sputtering and evaporation.
8. Define etch rate and selectivity.
9. How an isotropic and anisotropic etch profile looks like and why?
10. Explain how anisotropic etching is influenced by crystallographic orientation of the substrate.
11. Explain the mechanism of dry etching in general.
12. Explain how chemical and physical processes take part in the mechanism of deep reactive ion etching.

Lecture 3 (Neuronal recordings)

1. Draw the waveform of an action potential denoting the relevant phases, time- and voltage scales.
2. Define signal-to-noise ration. Mention some of the typical sources of noise during neuronal recordings.
3. What type of microelectrodes/probes are used to measure extracellular potentials?
4. What is the difference between EEG and ECoG recordings?
5. Characterize neural signals like action potentials, LFP, EEG and ECoG in terms of signal amplitude and frequency domain.
6. What are the major differences between microwire arrays and planar silicon probes?
7. Draw a schematic showing the major steps of the fabrication scheme of commercially available Michigan-type probes.
8. What are the advantages and disadvantages of Utah arrays compared to Michigan-type probes?
9. List the components of an equivalent circuit model of a recording setup.

Lecture 4 (Probes with active electronics)

1. Describe the typical detection range of single neurons when using depth recording electrodes.
2. Explain the technological challenge of developing high-density recording probes.
3. Draw schematics showing the typical architecture of active probes.
4. List typical signal processing functionalities typically implemented integrated circuits on the probe backbone.
5. Describe a biological event which can be efficiently observed with high-density recording probes.

Lecture 5 (Material properties)

1. What is the main difference between an insulator and a conductor (e- energy band theory)? What is role of the substrate and the encapsulation materials (including 1-1 specific examples)?
2. What is the difference between polymers and plastics?
3. Compare soft and rigid interface substrates. Highlight advantages and disadvantages of their applications.
4. List the relevant thermal, mechanical and electrical properties that are usually used to characterize substrates of neural interfaces.
5. What does mechanical mismatch between the device and the tissue mean?
6. Define Young's modulus.
7. What is the relationship between the thermal noise and the electrode impedance?
8. Explain electrochemical impedance spectroscopy. Describe the representation of related data in a Bode-plot.
9. What are the advantages of SEM compared to light microscopy?

Lecture 6 (Soft polymer implants)

1. How can derive the expected lifetime of a device using accelerated ageing tests?
2. Describe the equivalent circuit model of an electrode-electrolyte interface. What does each component mean?
3. List polymer substrates (at least five) usually used to fabricate microscale neural interfaces.
4. Characterize polyimide in terms of material properties and processing.
5. Draw the fabrication scheme of a typical polymer ECoG.
6. Describe the significance of electroplating in the technology of neural interfaces. How can we measure the improvement in electroactive surface area?
7. Explain the shape-memory effect. Draw a characteristic relationship between temperature and Young's modulus of a shape-memory material.
8. Describe how chemoresponsive polymers are changing their softness to external conditions.
9. Compare typical polymers with silicon and brain tissue by characterizing their Young's modulus.

Lecture 7 (Optogenetic probes)

1. Explain the basics of optogenetics.
2. Compare electrical stimulation and optogenetics.
3. Why is the relative position of signal and supply lines is important in the case of active optrodes?
4. How we can mitigate the extent of photoelectric artefacts in our recordings when using visible light optrodes?
5. Compare the optical properties of LASER and LED sources in general.
6. Explain the theory of total internal reflection.
7. Explain the photoelectric artefact.
8. List pair of thin film materials that are used to form integrated waveguides.
9. Describe the evanescent field of a waveguide. What is the significance of that in the case of designing the cladding layer of a waveguide?
10. List pro and contra for passive and active devices for optogenetics stimulation.
11. Explain the issue of self-heating of integrated light sources. What temperature increase is acceptable and why?
12. Describe an integrated solution for on-chip temperature sensing.

Lecture 8 (Infrared neural stimulation)

1. Compare optogenetics with infrared neural stimulation.
2. Most of the studies on INS work with excitation wavelength of around 1800-2000 nm. Why?
3. Explain strategies to form IR light delivery functions on implantable microelectrodes.
4. Describe loss mechanisms along the integrated waveguide of an optrode device.
5. Draw a schematic on how the beam shape exiting a waveguide can be characterized. Denote each component with captions.
6. How the spike of cortical cells change in the case of infrared neural inhibition?
7. Explain why silicon is appropriate to act as both mechanical carrier and a waveguide for INS?
8. How the coupling efficiency from an optical fiber to an optrode will change if the core diameter of the fiber increases?
9. How the spot size is defined?
10. Draw a figure showing the relationship of optical power and temperature when using INS.
11. What are the limitations of Utah type IR optrode compared to Michigan-type IR optrode?

Lecture 9 (Drug delivery probes)

1. List five medical applications of microscale drug delivery.
2. What parameters determines the flow rate in the case of iontophoretic injection of charged particles?
3. What parameters determine hydrodynamic resistance in a microchannel?
4. Draw the schematic process flow of surface-, bulk micromachining approaches to fabricate microfluidic channels.
5. What is the relationship between pressure and flow rate in a laminar flow?
6. What dimensional and material parameters determine the buckling force of a hollow needle?
7. How does the steepness of pressure flow rate curve changes if the length of the microchannel increased?
8. What is the operation principle of thermally actuated integrated micropump?
9. What is the effect of elastic components on flow profile?

Lecture 10 (Mechanical considerations)

1. List relevant device properties that have influence on device-tissue interactions.
2. List the main sources of mechanical interactions between device and tissue.
3. How does an integrated bulk component change response of needle-like implants to bending and buckling loads?
4. What is residual stress in MEMS devices and why it is important?
5. What is the relationship between buckling and fracture? What is the critical buckling force of a needle?
6. What is tissue dimpling during device penetration, and why it is important to be reduced?
7. What is the effect of device geometry on insertion forces and dimpling measured during implantation ?
8. What is tethered and untethered probe configuration?
9. Describe micromotions inside the brain. What kind of forces are induced around the implants due to micromotions?
10. What is the relationship between insertion speed and penetration forces?
11. Describe the relevance of responsive neural implants regarding their mechanical properties.

Lecture 11 (Long-term stability)

1. What is the composition of brain tissue?
   (cell types, micro environment)
2. What is cell adhesion and why is it important?
3. What are the main reasons for tissue damage?
4. What are parameters are important to measure during stability tests?
5. Describe the major stratetegies currently used to increase long-term stability of neural implants.
6. Describe the major consequences of nanostructuring.
7. How can we improve longevity using specific coatings? Describe an example from literature.