Our approach...

Micromachined, high-resolution, microwave diagnostic tool for skin cancer.

Joachim Oberhammer, KTH; FSM workshop, 2019-06-18; joachimo@kth.se
KTH’s micromachined mm-wave skin-cancer probe

Töpfer, Dudorov, Oberhammer, *IEEE IMS 2012*.
**Probe size and design**

*Subwavelength probe tip size:*

- 0.2\(\lambda\) in skin tissue at 100GHz

- Tapered dielectric-rod waveguide (metallized Silicon-core)
- Optimized broad-band dielectric wedge transition
- WR-10 waveguide (75-110GHz)

- Probe tip (non metallized)
- HRSS: 4000\(\Omega\)cm
- \(\tan\delta=6\times10^{-4}\)
- Au: 1.4\(\mu\)m

- WR-10 WG

- Probe tip

- (dim. in mm)

- Töpfer et al, *IEEE IMS 2012*.

Joachim Oberhammer, KTH; FSM workshop, 2019-06-18; joachimo@kth.se
Design & simulations

@100 GHz

CST Microwave Studio, FDTD

Joachim Oberhammer, KTH; FSM workshop, 2019-06-18; joachimo@kth.se
Calibration with silicon of ‘tailor-made’ permittivity

Sub-wavelength perforated silicon:
- permittivity by design from 1.5 to 10
- losses by using doped substrate
- micromachined (DRIEetched)

Töpfer, Dudorov, Oberhammer, *IEEE MEMS 2013.*
Technical probe characterization

- high responsivity
- high reproducibility (<1.5%)
- high stability (<0.6%/6h)

Töpfer, Dudorov, Oberhammer, IEEE IMS 2012.
• lateral resolution ~100um
• tested on tailor-made samples mimicking permittivity modulation corresponding to healthy and cancer tissue

Töpfer, Dudorov, Oberhammer, IEEE MEMS 2013.
Part 5. In-vivo studies
Measurement setup for on-skin measurements

X-y-z stage to move probe onto and over skin

Micromachined millimeter-wave probe, connected to VNA through standard waveguide

E8163A Agilent vector network analyzer (VNA) with millimeter-wave extender heads, up to 110 GHz

Arm of test subject (here: my supervisor)
Measurements on different body sites

- Different $S_{11}$ measured on different body sites → for skin cancer diagnostics reference measurement on surrounding tissue required

Töpfer, Dudorov, Oberhammer, *IEEE IMS 2014.*
Skin burn measurements

- Clear differences in $S_{11}$ measurements with our mm-wave probe between burned, newly grown and normal skin.

Töpfer, Dudorov, Oberhammer, *IEEE IMS 2014.*
Monitoring of skin healing process

- day 5: normal/new/burnt still distinguishable
- day 7: normal/new indistinguishable; burnt approaching normal
Discrimination between benign skin neoplasms and subdermal nevi.

- Higher water content is associated with raised moles.
- Lower water content is associated with subdermal moles.

References:

Joachim Oberhammer, KTH; FSM workshop, 2019-06-18; joachimo@kth.se
Profile scan over intradermal nevus

KTH microwave measurements:
- clear correlation with nevus

TEWL reference measurements
- not stable/reproducible low signal

Töpfer, Dudorov, Oberhammer, *IEEE IMS 2014.*
Standardized dermatological tests

- artificially stimulated skin irritation with chemicals, similar to allergy tests
- patches with different concentration levels (0%, 1%, 2%, 5%, 10%) applied for 24 hours
- monitored every day
- references:
  - examination by dermatologist
  - trans-epidermal water-loss instrument

Töpfer, IEEE IMS 2014.
Monitoring of irritant skin reactions

Skin irritation with sodium-lauryl-sulphate (24 hours, 10%, 5%, 2%, 1%, 0%)

- **Microwave measurements with KTH probe:**

- **Reference measurements:** TEWL dermatological instrument (Khazaka TM300)
Probe pressure operator independency

- stable signal after skin displacement of ~0.1mm
It works – what’s next?

Studies on real melanoma.
Murine skin cancer model

- 6-weeks-old female athymic Nude-Foxn1\textsuperscript{nu} mice
- Subcutaneous injection of 0.5 million $10^6$ B16F10 murine melanoma cells in 200 µl PBS
- Palpable tumor of ~1 cm size after 12 – 14 days → termination
Measurement setup

- Mouse anesthetized during measurement
- Heating mat and temperature sensor for stable mouse body temperature
- Millimeter-wave probe
- VNA
- x-y-z stage to move probe
Results: Histology

- **Mouse 1**
  - Skin layer ≈ 100 µm
  - Tumor
  - Tumor inside skin
  - represents **realistic** skin tumor

- **Mouse 2**
  - Skin and fat layer ≈ 600 µm
  - Tumor
  - Tumor beneath skin and fat
  - **not** representing skin cancer
Murine skin cancer model

**Mouse 1:** Tumor inside skin (represents **realistic** skin tumor)

**Mouse 2:** Tumor beneath skin (not representing skin cancer)

- Clear difference in $S_{11}$ between the realistic tumor and the surrounding tissue (6.7 times the average stand. deviations on the same spot)
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Conclusions

• microwave interaction with tissue exists and can be used for medical diagnosis
• millimeter and submillimeter-wave frequencies offer many opportunities in medical diagnosis
• a tailor-made, micromachined 100 GHz near-field probe for skin cancer diagnosis was designed and implemented
• successfully characterized was carried out technically and in-vivo, on human and animal models
• the sensor is clearly able to discriminate melanoma from healthy tissue at the targeted tissue depth