Deicing of Wind Turbines using Microwave Technology

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Support:
Swedish Energy Agency

SP Technical Research Institute of Sweden

RE • TURN

ICE SOLUTION

Agenda

- Background, ”Micro-Deice” consortium, objectives
- Microwave De-icing and CNT coatings
- Energy demand (deicing and anti-icing)
- Proposed solutions, microwave systems
- Summary

Project history: TopNANO and DEICE

NICe, Budget ca. 3 M€, 2011-2014

R&D: SP (coordinator), KTH (SE), Aarhus Univ. (DK) and VTT (FI)

Industry: SAAB, Vattenfall, Electrolux, Nibe, Danfoss, SAPA (Gränges) , MW Innovation, Re-Turn, n-Tec

Targets: heavy-duty coatings with no / reduced ice adhesion in three sectors: **windpower, aircraft and heat exchangers**

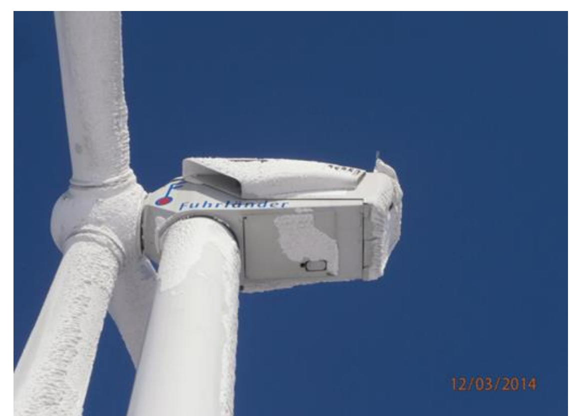
NFR, Budget ca. 4 M€, 2011-2014

Industry: Re-Turn, n-Tec, (IFE)

Targets: CNT coatings, electrothermal heaters → microwave deicing

Output: 4 patent appl., new company Icesolution AS (SE/NO)

www.topnano.se



Micro-Deice – Objectives

- Proof-of-concept: combine energy-efficient microwave deicing with a durable top-coating with low ice/water adhesion, building on TOPNANO
- Ensure lightning protection and HSE aspects
  - **Optimization** wrt MW absorption and heat generation.
  - Combination of **active** and **passive** coatings.
  - **Ageing** properties.
  - Formulations optimized for **spray coating**
  - **Scale-up** trials, prepare field trials
  - **Microwave sources**, incl. wave guides for field tests
  - Health & Safety, incl. **lightning** sensitivity

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Micro-DeIce combines Active & passive De-icing

- **SP** coordinator, lab scale development work, testing, etc. Experience with materials, RF, lightning, risk analysis, TOPNANO background
- **Re-Turn AS** developer of technology, microwave absorbent supplier, Experience: marine coatings, CNT processing, composites (HV), DEICE
- **MW Innovation AB** consultant, Topnano partner: Experience from electrical deicing heating foils
- **Pegil Innovations AB** supplier of MW sources, incl. Waveguides, Experience: MW drying ovens, construction
- **Vattenfall R&D AB** potential end-user of the technology

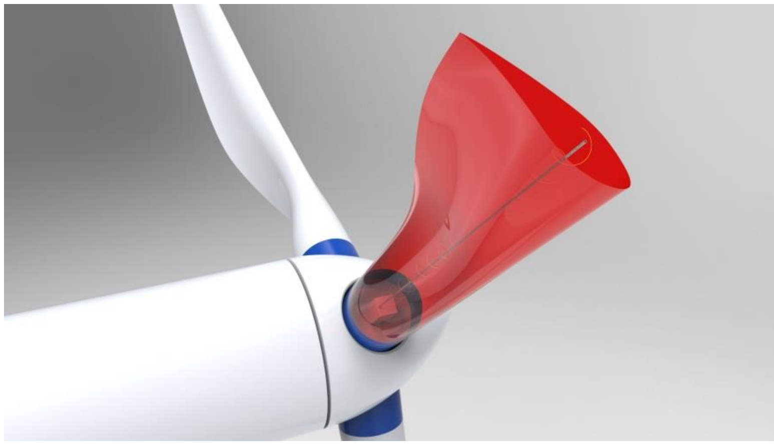
- **Network** of R&D (KIT), chemistry (Arkema), experts, finance, end-users

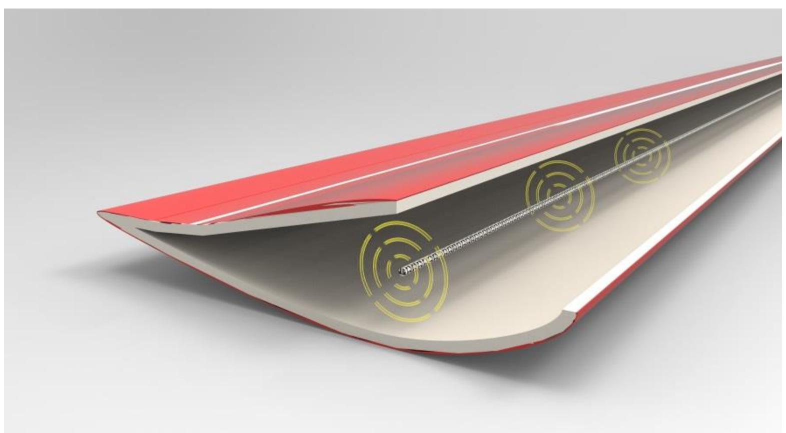
Project duration: sep 2013-aug 2015, budget: ca. 350 k€

Sponsor: Swedish Energy Agency

Introduction CNT coating / MW / results

Introduction to Microwave De-Icing





Technology

- Carbon Nanoparticles in a coating or film absorb MW radiation and generate heat
- Special innovation: coating itself
- Microwave generators inside the blades (ideal)

New installation or Retro-fit

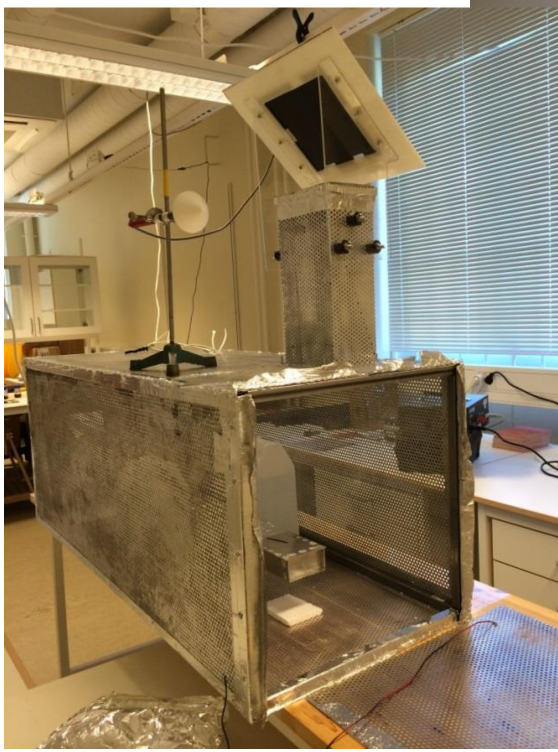
- Mechanically safe installation of MW generator and waveguide
- Stretch target: Anti-icing functionality

Status

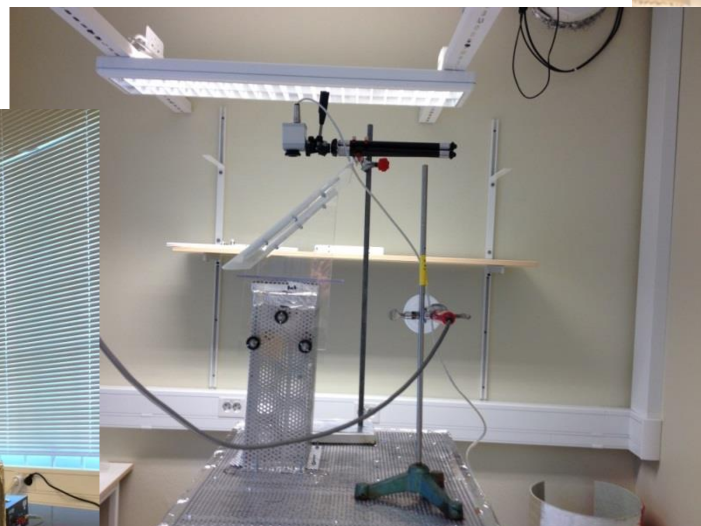
- Prototype operating in cold lab (-20 ^{o}C)
- Economic estimates encouraging
- Proof of concept tbd

Coating characterization

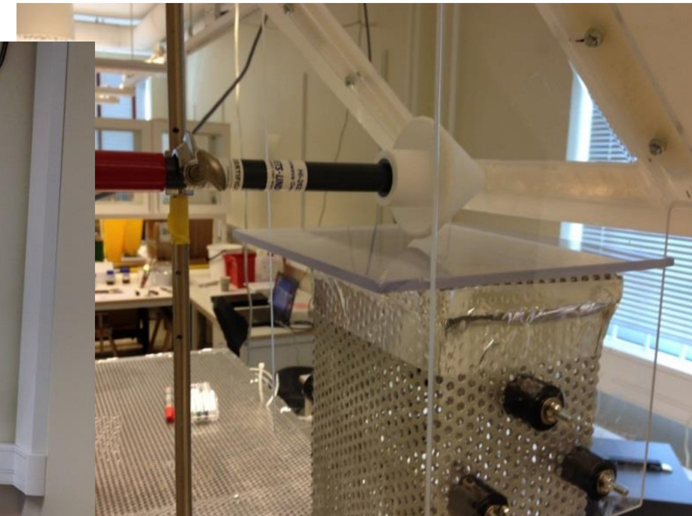
Reflectance setup

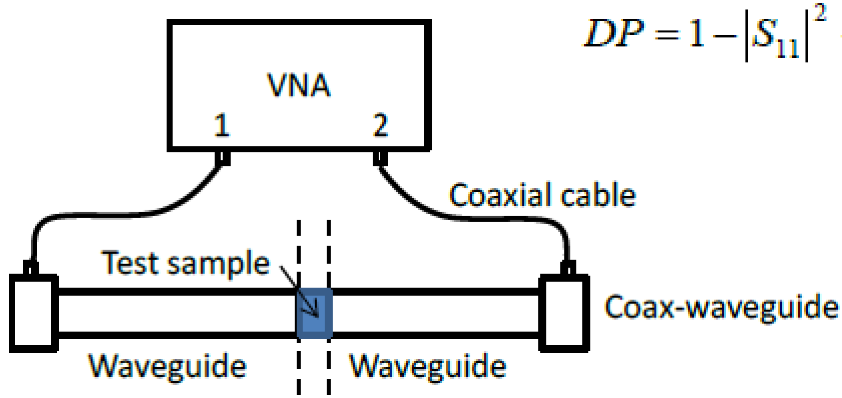


IR camera setup



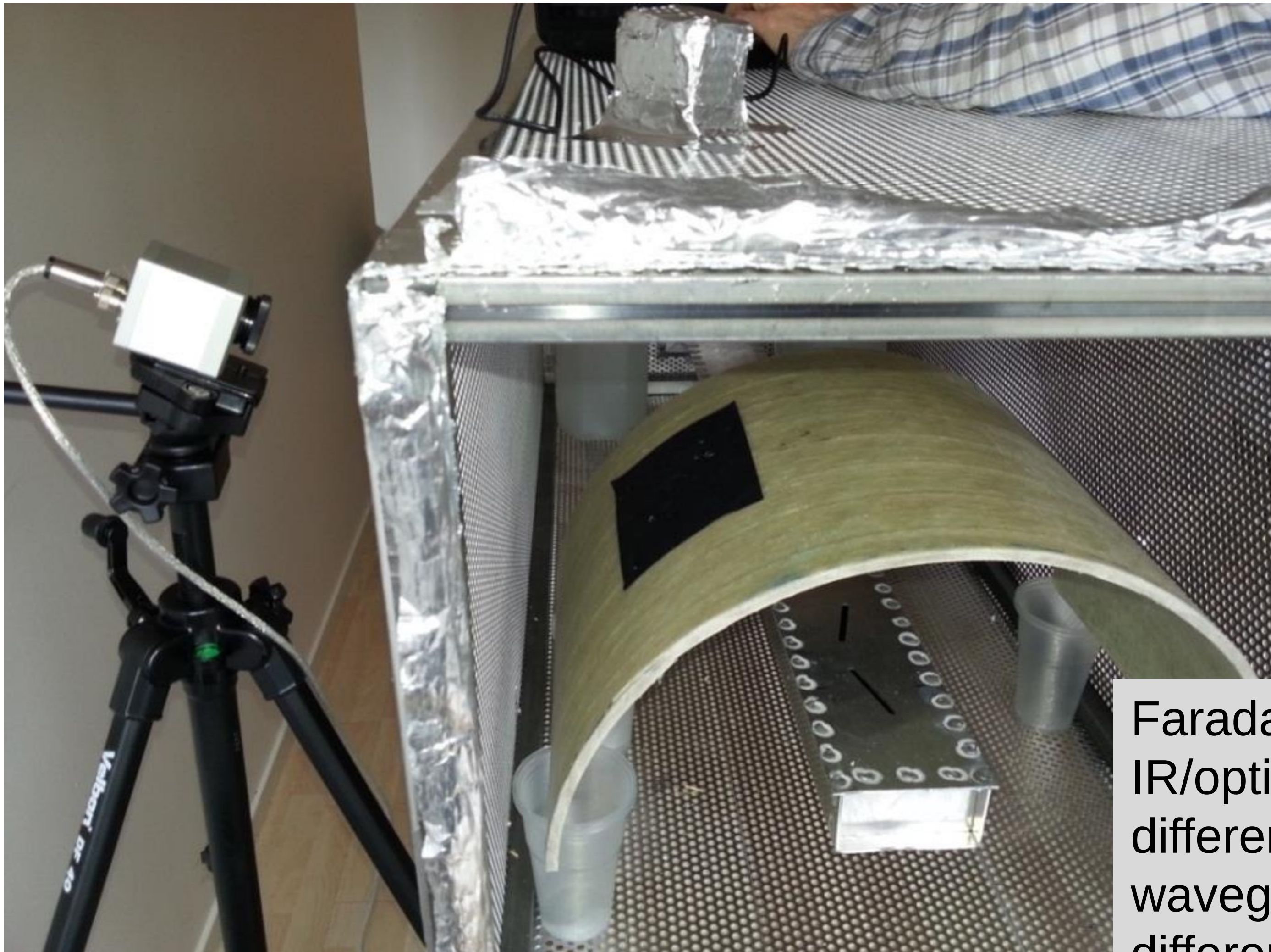
Transmittance setup





$$DP = 1 - |S_{11}|^2 - |S_{21}|^2$$

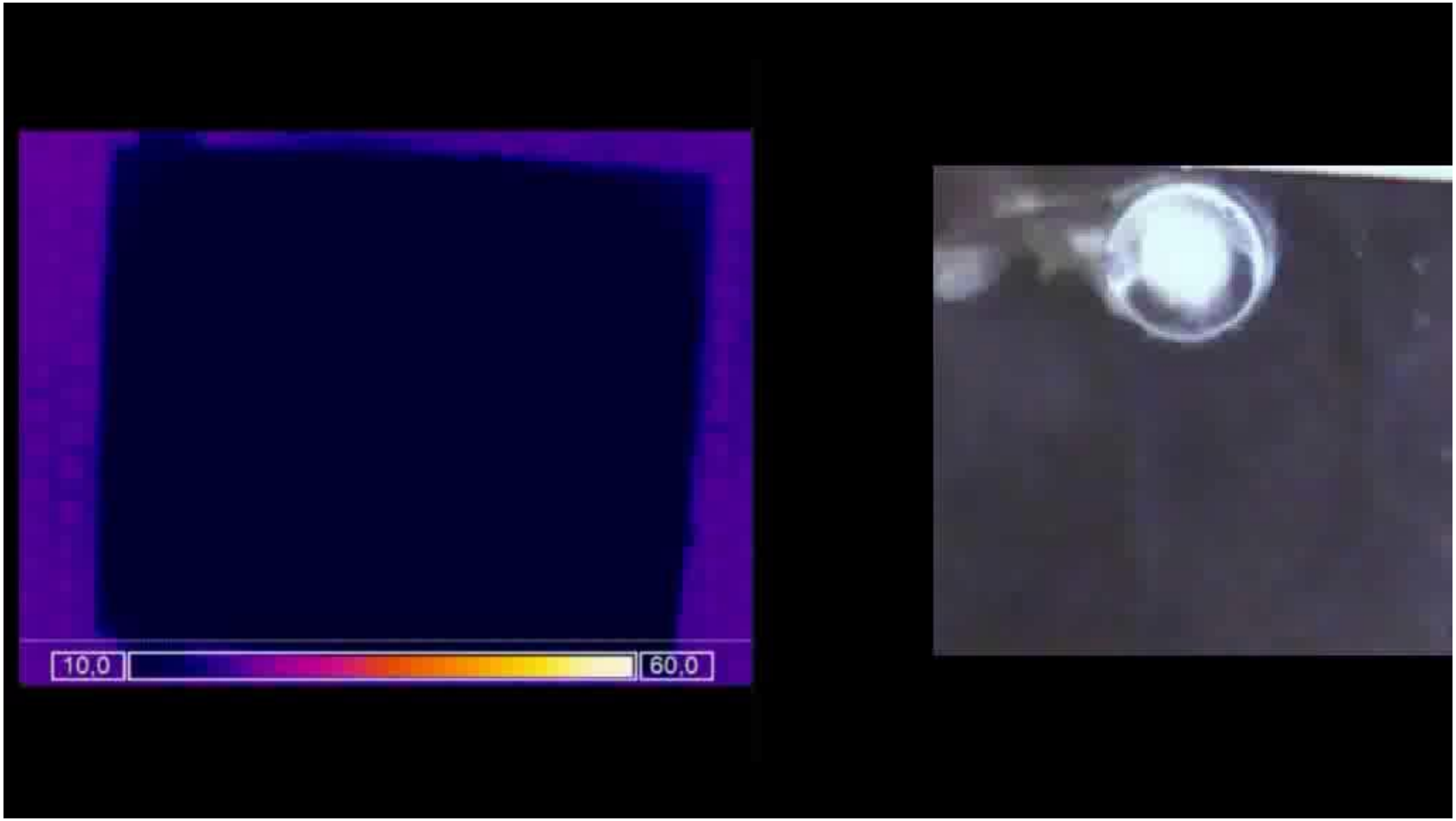
Screening of coatings



Faraday cage, IR/optical cameras, different waveguides, different foils and coatings

Microwave heating of a small sample (PU coating with CNT)

Infrared camera **web camera**



2*2 cm ice cube ”glued” onto glaze ice, start -20 ^{o}C
Tilted surface

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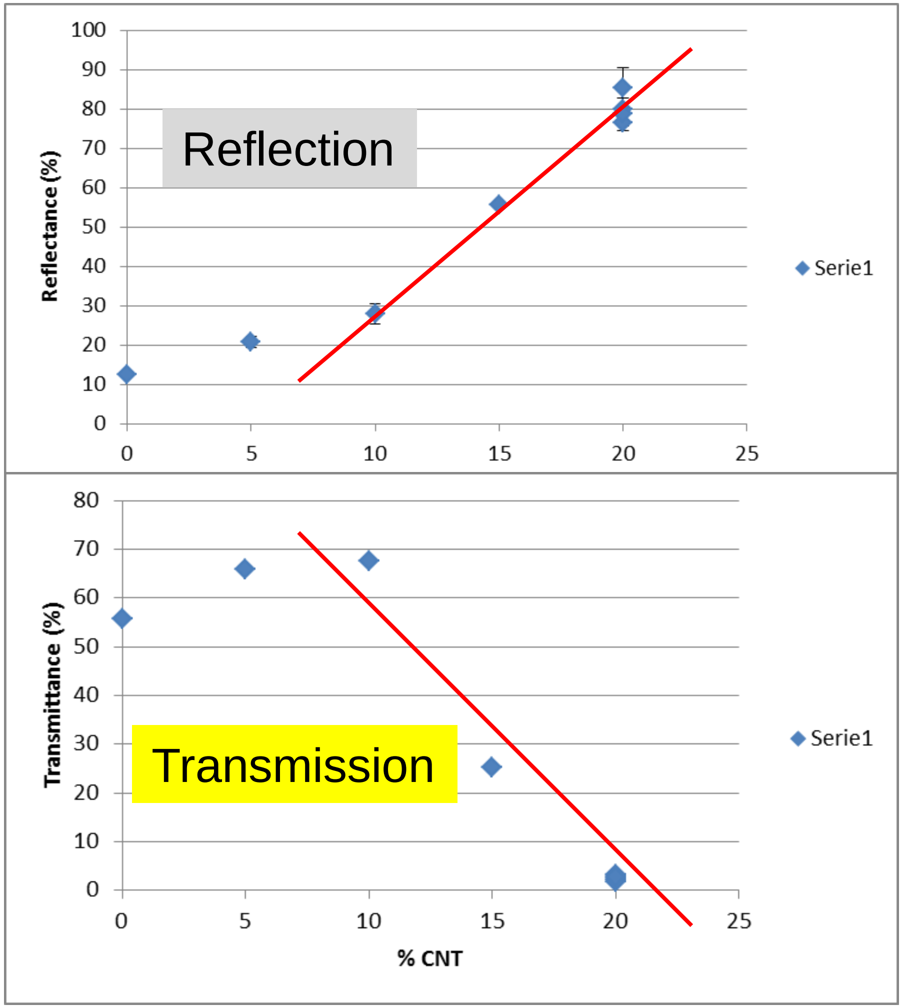
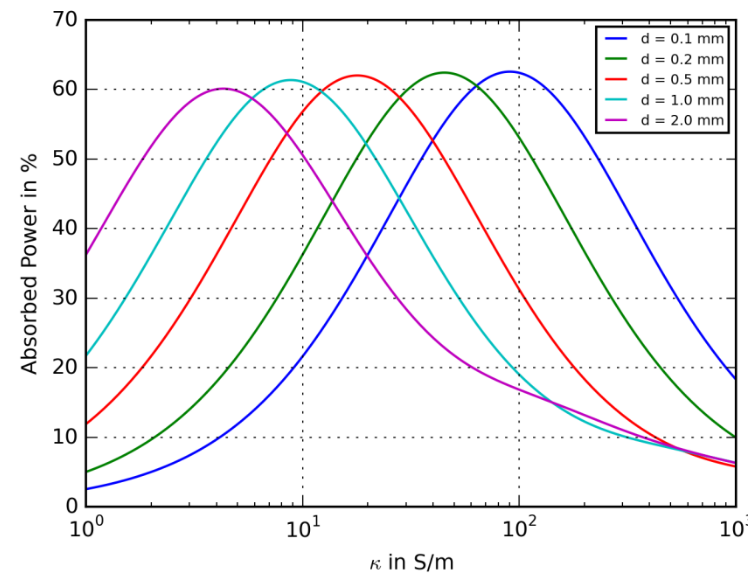
Increasing CNT content → absorption of MW



15-20% wt. CNT in MW-absorbing coating (ca. 100 micron) is a good compromise between reflection and absorption of MW. (Reflex is also absorbed.)

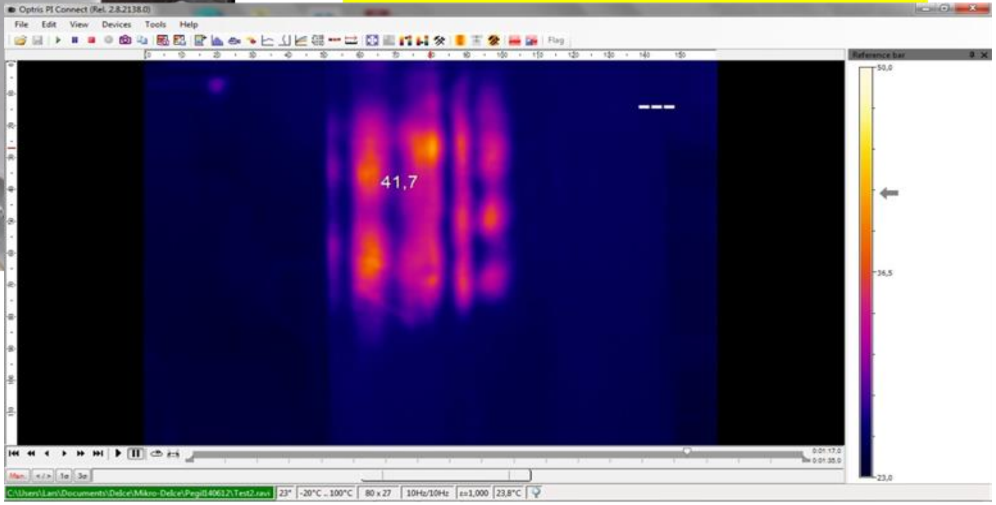
Coating is semiconducting. Dispersion and matrix influence.

Actually, physics is non-linear...



Results Micro-Deice (Skövde 2,5 m segment)

< 400 W/m2 for 1 min only!

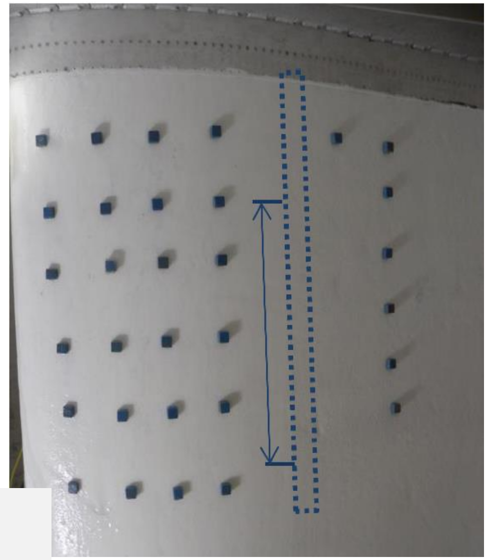


Leading edge heating using 2,45 GHz magnetron and waveguide:
Efficient, but spatial variation

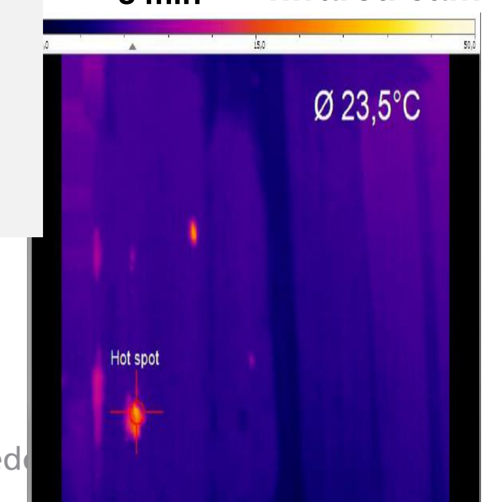
Successful -20 ^{o}C deicing, sep 2014

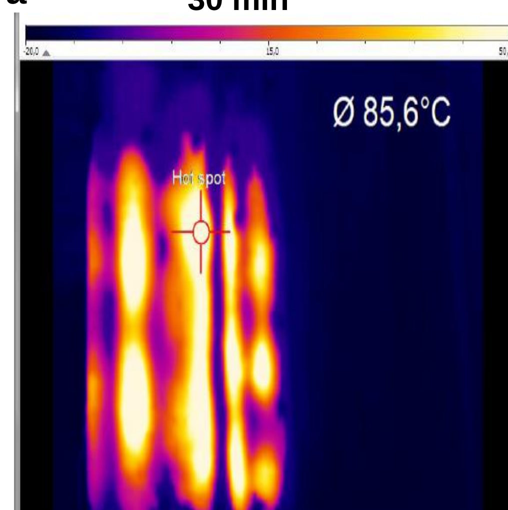
Sep 2014 De-icing trials at -20 °C

Before **web camera** **After**



5 min **Infrared camera** **30 min**





Tough ice removed in 10-30 min
Learnings:

- Coating should be heat-conductive and hydrophobic,
- MW should be ”intelligent” and self-regulating

Summary of microwave / coating tests

- CNT coatings are extremely good microwave absorbers
- 100 micron coatings fit for purpose. Patent appl coating submitted.
- Most MW radiation is absorbed and heats the coating. Negligible loss.
- Reflected radiation is re-absorbed, reflection levels out local temperature differences, caused by wavelength effect (12 cm).

- Preliminary OK for use of aluminium waveguides regarding lightning, provided > 1 mm aluminium is used.
- Annoying spatial variation of 2,45 GHz MW intensity (10 K temp delta)
- Concerns about mechanical stability of alu waveguide (blade flex), possible fix = flexible flanges

- In view of energy demand, search started for better MW generators.

Energy demand for deicing / anti-icing

https://macsphere.mcmaster.ca/bitstream/11375/15330/1/fulltext.pdf

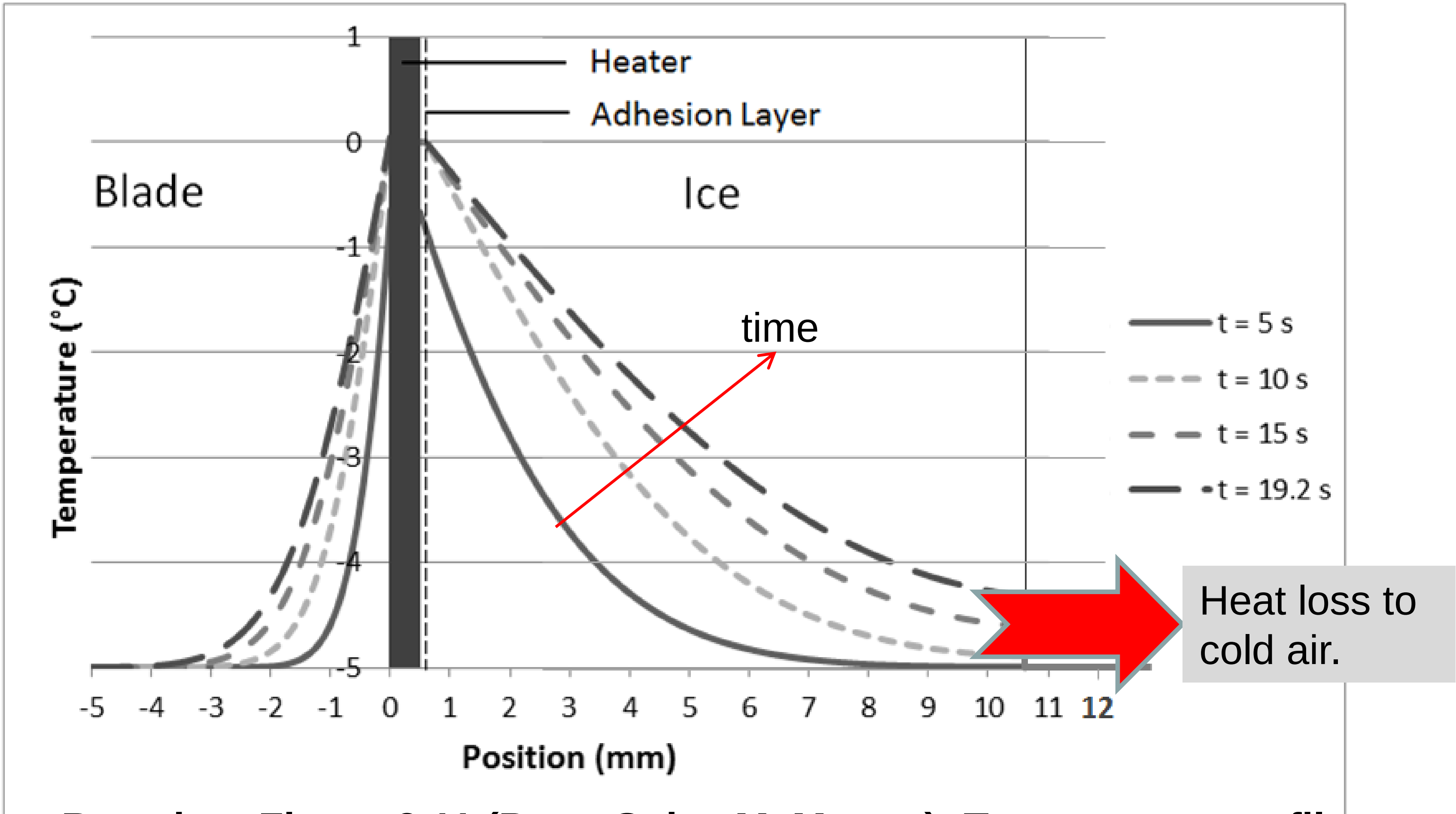
Peter Suke, McMaster University, Ontario, CA

Analysis of heating systems to mitigate ice accretion on wind turbine blades

Important parameters:

Heat supply – heat conductivity (layer by layer) –
heat enthalpies (all materials) – melting enthalpy ice –
Ice layer thickness which requires melting …..
AND: heat loss to ambient air!

Numerical solutions required (Fourier)



Based on Figure 3.11 (Peter Suke, McMaster): Temperature profiles through the ice and the blade skin, using numerical simulation. Base case conditions, see Table 3.2 for details.

High power, e.g. 5 kW/m² → less 20 sec deicing time
Low temperature → longer deicing time. 1 kW min?

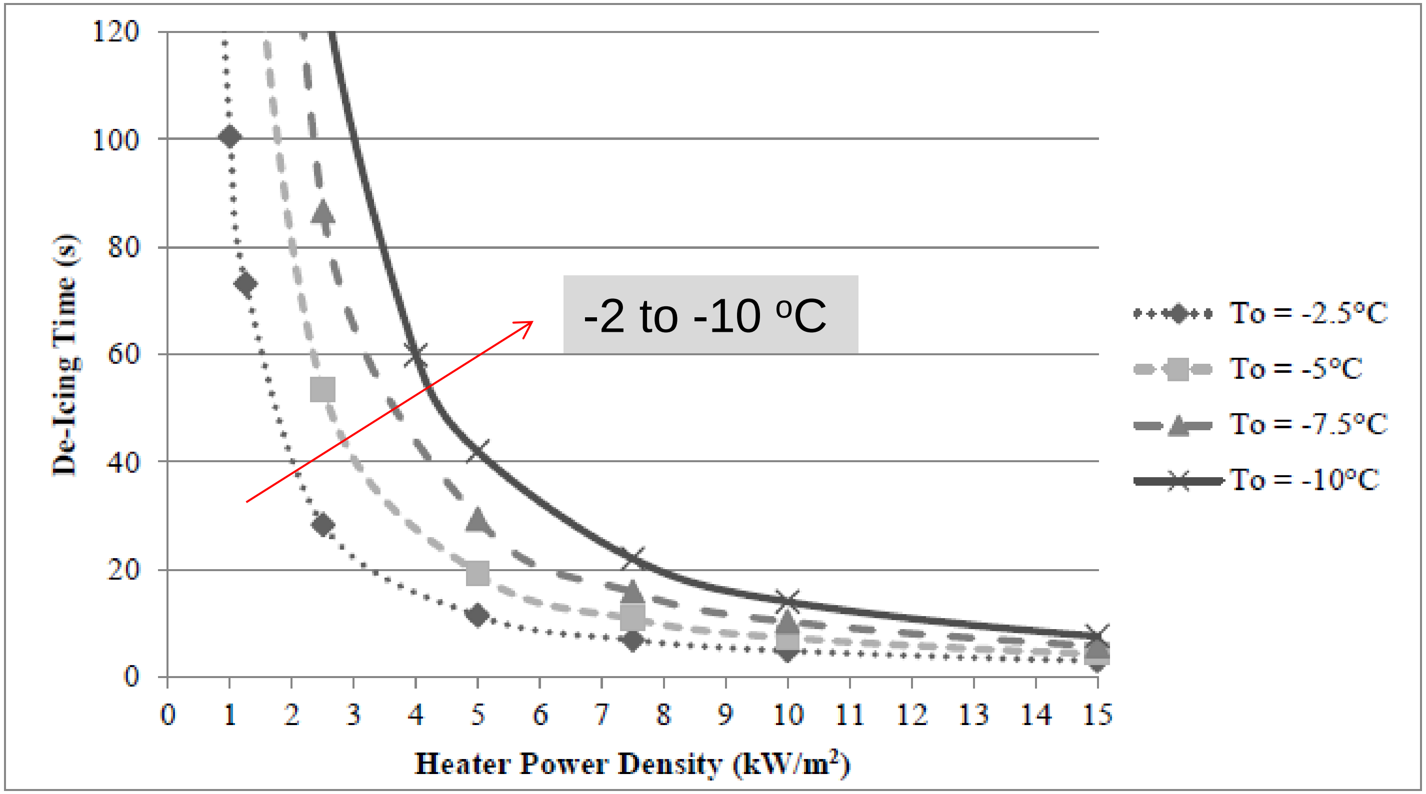


Figure 3.13: Effect of heater power density and ambient temperature on the base case (Table 3.2)

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Peter Suke, McMaster Univ, Ontario

Thick ice layer insulates → easier deicing (less W/m2 requ'd)

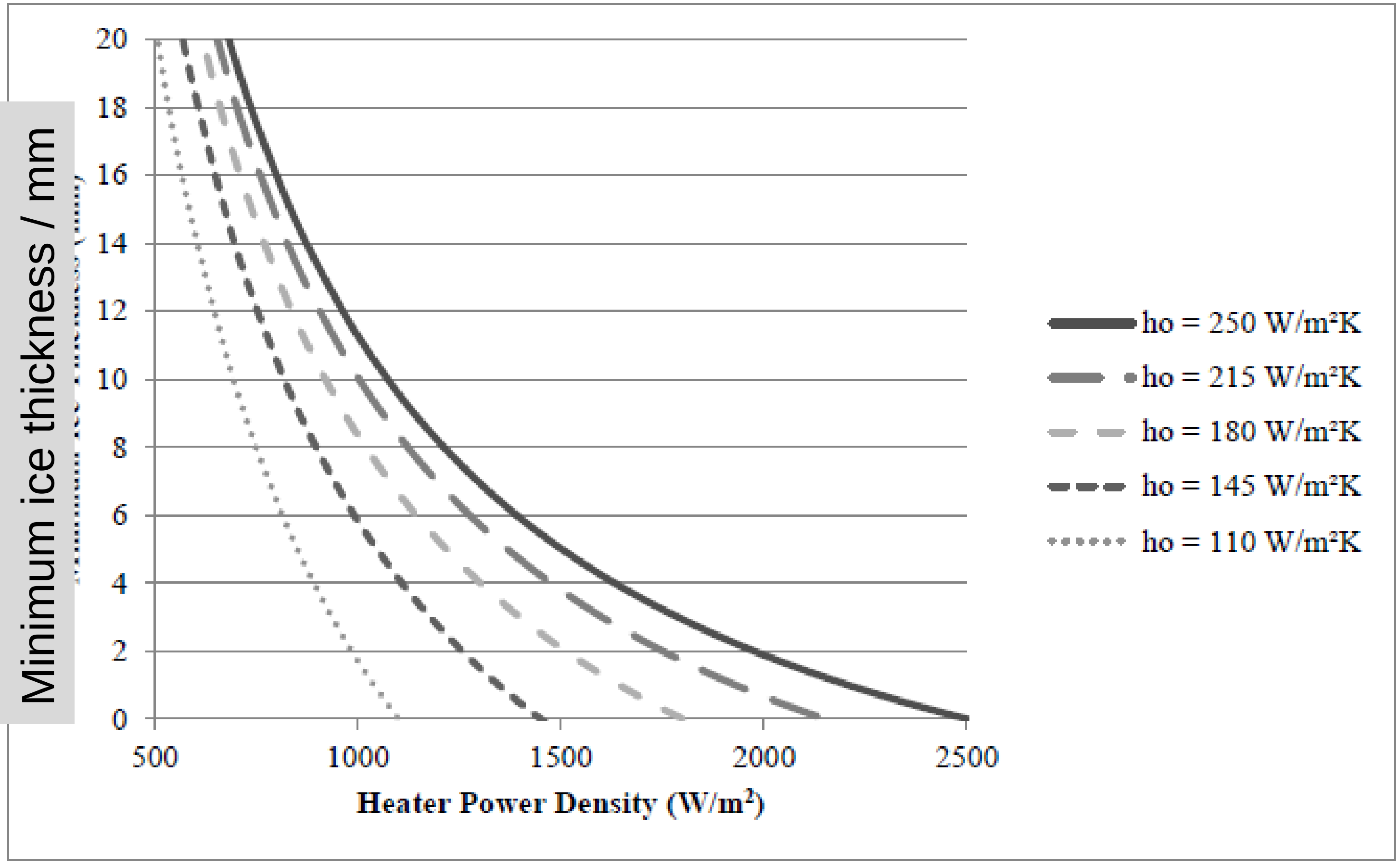

Figure 3.18: Minimum ice thickness required for de-icing. Ambient temperature, To is -10°C, and the type of ice is glaze.

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Hot air (100 °C):

Insulating core is a bottleneck for heat flow.

Most/all heat is lost to ambient air before it can melt the adhesion layer.

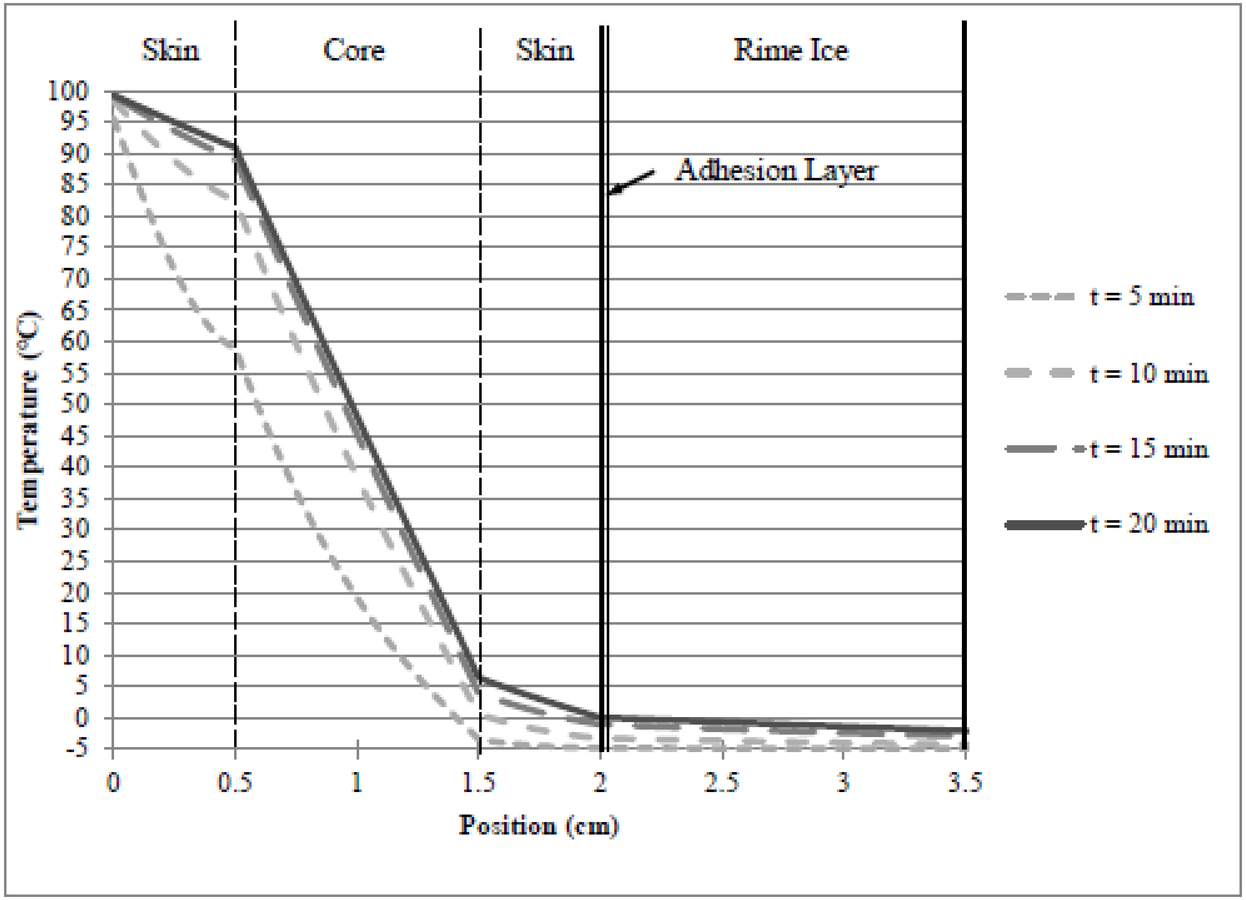


Figure 4.7: Temperature profile through the blade and ice with time. The initial temperature is equal to the ambient temperature of -5°C. The inner blade wall is maintained at 100°C. The fibreglass skins are 5 mm thick each and have a conductivity and heat capacity of 0.18 W/mK and 1600 J/kgK, respectively. The foam core is 10 mm thick and has a conductivity and heat capacity of 0.032 W/mK and 1500 J/kgK. The ambient conditions are favourable (Table 4.3).

Peter Suke, McMaster Univ, Ontario

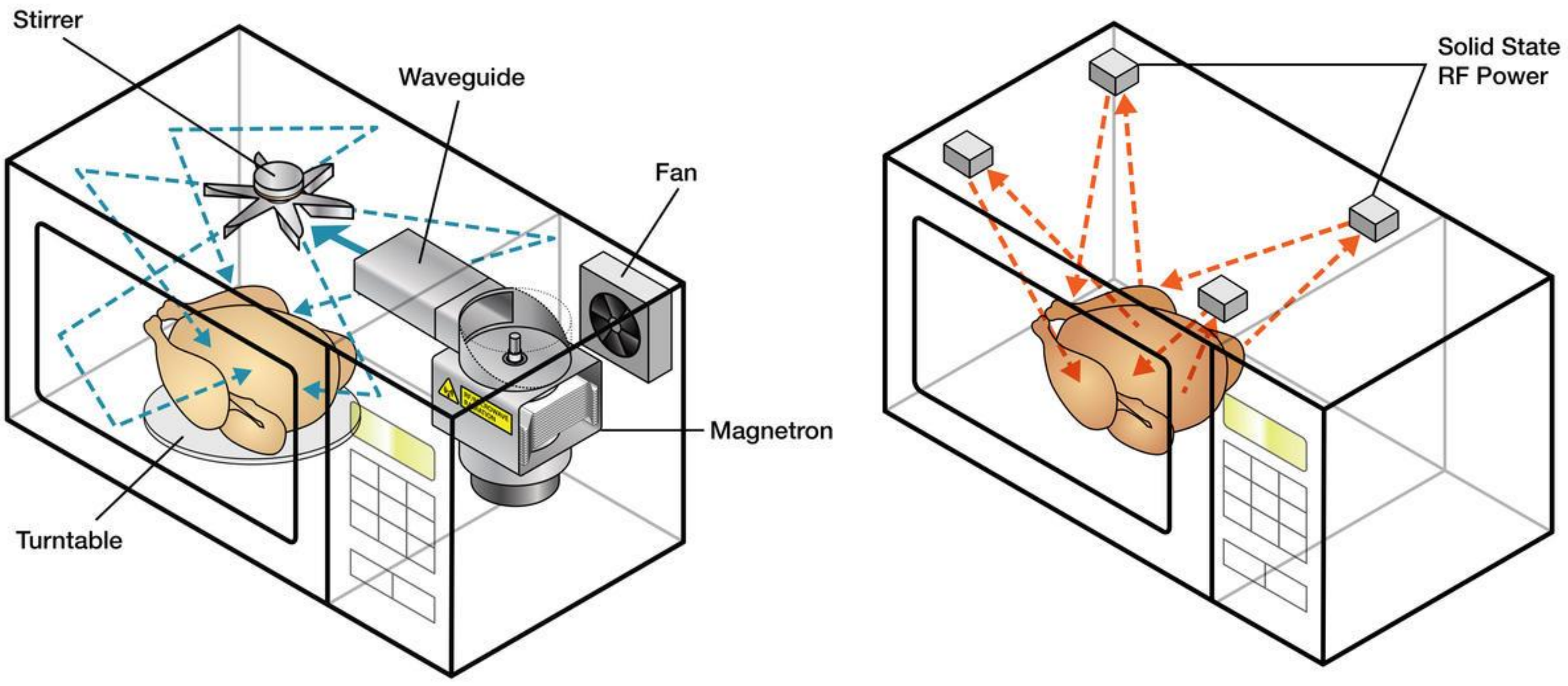
Summary Energy Demand

- Microwave heatable coatings for anti-icing or de-icing demonstrated in cold container environment (-20 ^{o}C), Laboratory tests in line with theory.
- Energy demand high due as ambient air “steals” heat quickly
- Ice layer thickness and ice type are important (for heat loss rate)
- Hot air solutions seriously disadvantaged
- MW and electrothermal heater: comparable heat flow parameters
- Quick heating close to surface essential, min. 1 kW/m^2 for deicing (stat.)
- Anti-icing: ca. 5 kW/m^2 required, especially at tip
- Sequential heating natural choice, depending on available power

Proposed solutions: MW deicing

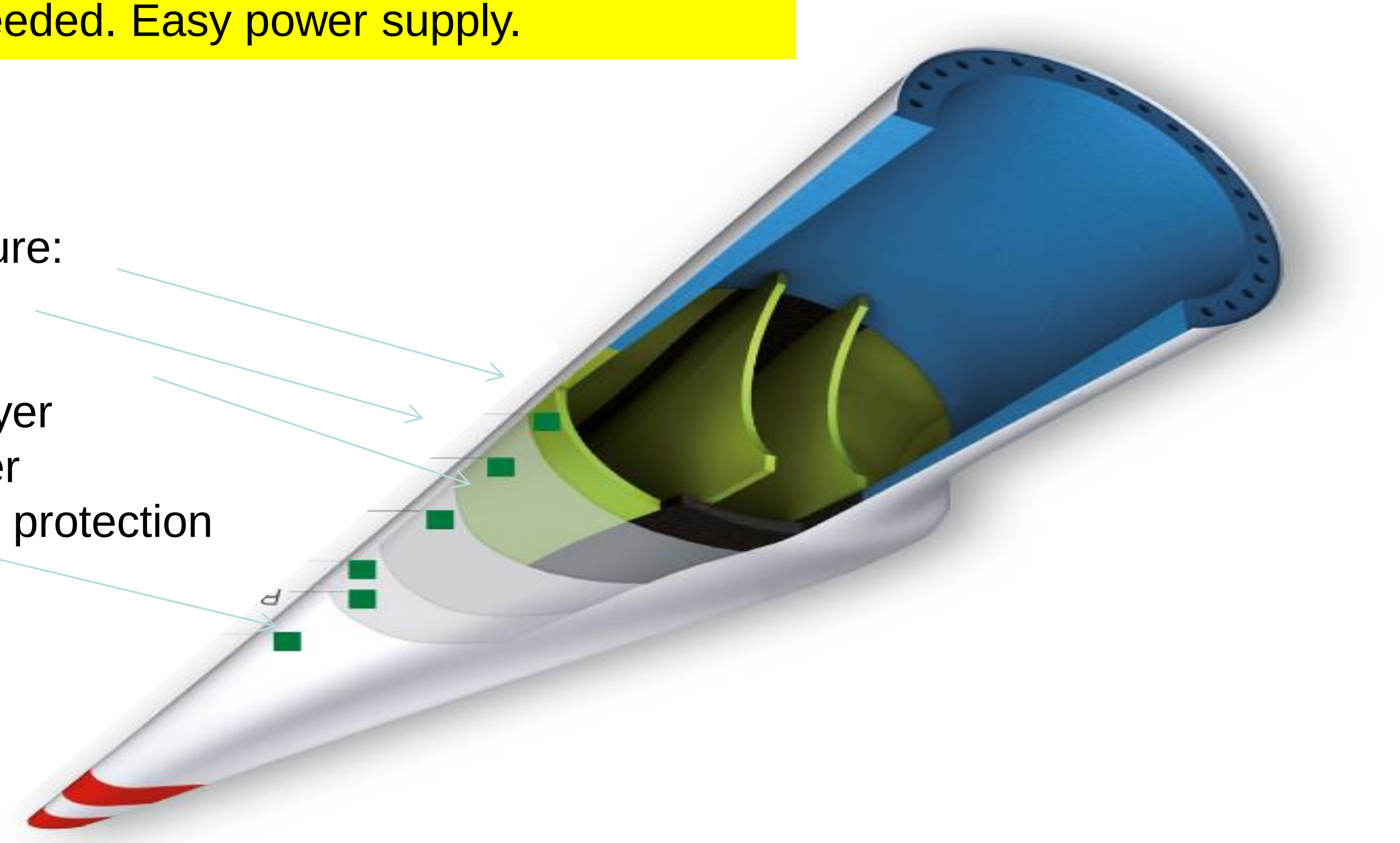
Semiconductor revolution in microwave heating technology

Transistors replace magnetrons – suitable for wind power.
Advantages: Lifetime (!) – weight – price – control (!) – ruggedness-design & installation options



Deicing: multitude of MW transistors (e.g. 250 W)
- fastening: dependent on blade design
- Coating on whole blade (radar and HSE),
- LE heating 1st option
- Transistors individually addressable
- No HV needed. Easy power supply.

Layer structure:
Laminate
Gelcoat
Insulating layer
MW absorber
Top coat, LE protection



Commercial offerings: MW deicing

Cooperation with turbine producer, design, production fit

Retrofit of existing turbines in CC: Analysis – Design – Solutions – Installation – Service

Options for field trial: only CNT coating, heating by skylift / MW panel, or internal MW sources

Benefit of CNT coating: less radio / radar disturbance

New study suggested to solve conflicts wind/air traffic!

Summary

- Microwave heatable coatings for anti-icing or de-icing demonstrated,
- Concept: a plurality of MW transistors (2,45 GHz), sequence deicing or anti-icing, various configurations possible (LE or tip only, external skylift, etc)
- Potentially cost disruptive
- “Wireless” solution, repair-friendly, flexible, ok for blade bend)
- Extra benefit: reduced radar interference
- Next phase: further upscaling in field tests, cooperation welcome!

Thank you for your attention!

Questions? joachim@re-turn.no

Come and see us at **Booth 39** in the Exhibition Hall here at Winterwind!

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