Anti-icing:

Surfaces, Technical Approaches and Status

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- General anti-ice aspects
- Evaluation of anti-ice coatings at Fraunhofer IFAM
  - Ice formation tests
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  - Investigations on icing mechanisms
  - Tests under real conditions
- Development of Anti-ice coating technologies
  - Active coating concepts
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- Outlook

Anti-ice coating concepts are relevant for varying technical fields

For example: **Means of transportation (aircrafts, cars and trains)**
Cooling units
Wind energy plants, Bridges, antennas and transmission lines

Effective anti-ice coatings:

COST REDUCTIONS AND SAFETY BENEFITS

General anti-ice aspects

Determining factors for the development of effective anti-ice coatings:

Icing conditions for the specific technical application

Further technical requirements on the coating

lead to

Tailor-made coatings for respective technical application

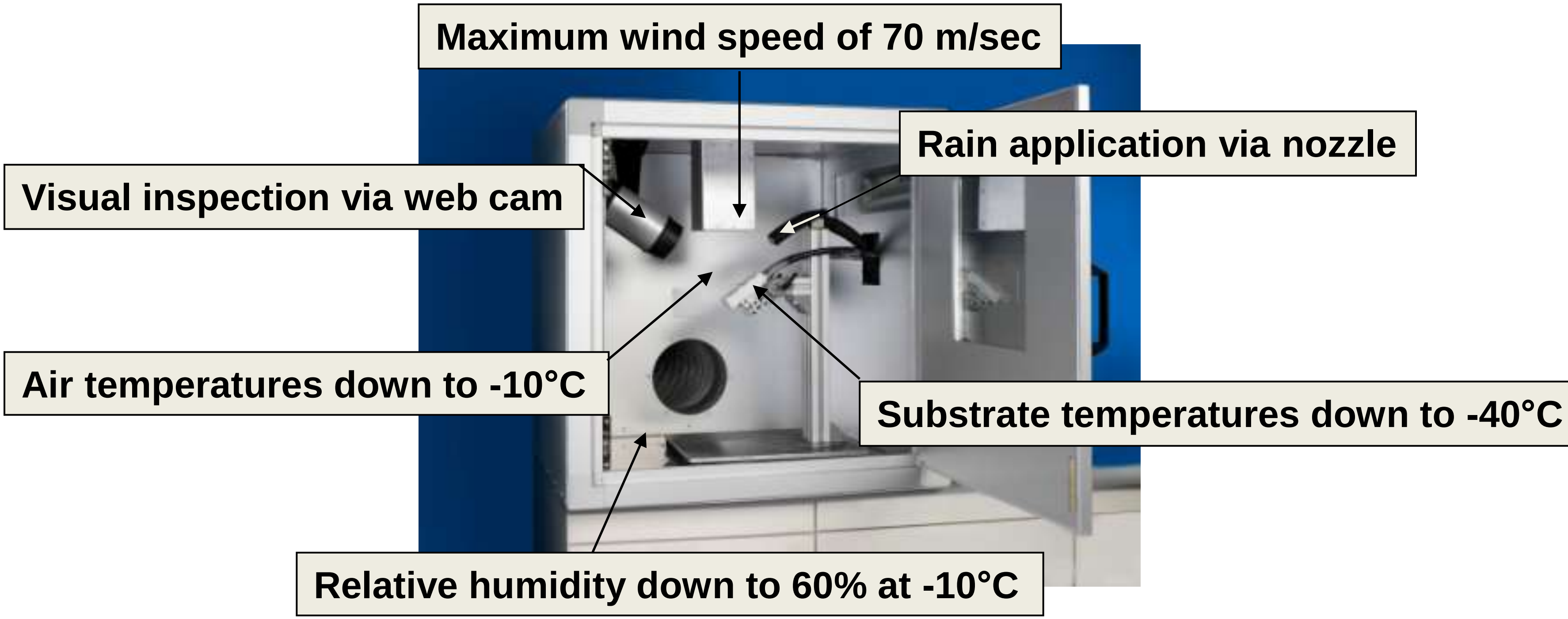
To achieve this you will need:

Ice test facilities

- taking into account relevant icing conditions,
- that are able to discriminate between new designed coatings regarding ice prevention or reduction,
- cover a broad range of ice tests to avoid misinterpretation

Ice formation tests

IFAM ice chamber for evaluation of anti-ice coatings:



Conventional approach for anti-icing: Hydrophobicity

IFAM ice chamber tests: standard test scenarios

Ice rain test:
Simulates run-off behaviour of water and subsequent formation of clear ice

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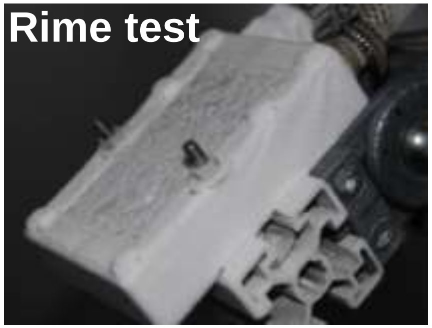
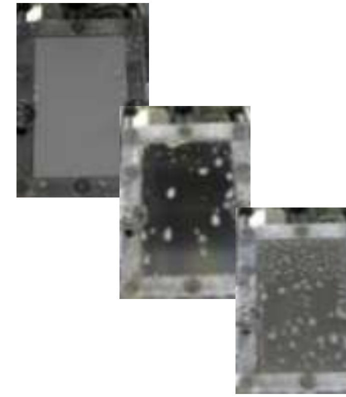
Ice formation tests



Simulates formation of rime



Simulates run-off behaviour of water and subsequent formation of clear ice

<u>Test conditions</u>

+1°C	**Air temperature**	-5°C
- 2°C	**Substrate temperature**	/
88%	**Relative humidity**	66%
9 m/sec	**Wind speed**	9 m/sec
/	**Rain duration**	10 seconds
rime thickness and adhesion	**Assessment**	visual inspection 10 min after raining

Ice formation tests

Development of test design with wing profile to

- **simulate ice accretion on leading edge and**
- **subsequent melting of ice, including runback ice formation**

Wing profile with freezed ice on leading edge:

Wing profile after defreezing the leading edge:

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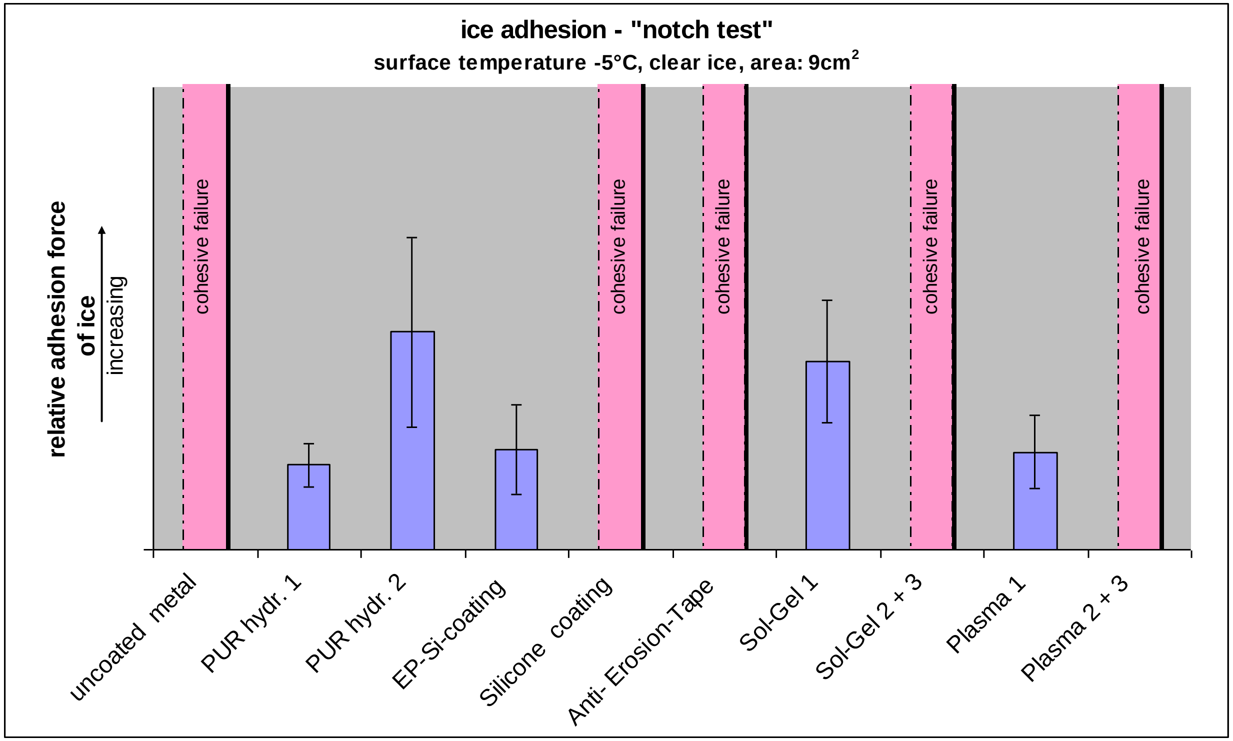
Ice adhesion tests

- **Pendulum test**:
  - ice cubes on test surface are knocked off by a pendulum
  - reduced energy of the pendulum is correlated to the adhesive strength of the clear ice, measured as angle of the pendulum amplitude

- **Centrifuge test**:
  - ice on test surfaces are removed by centrifugal force
  - piezo electric cells detect the impact of the detached ice layers

Ice adhesion testing: extract of results of notch test



→ Up to now no general coating type could be observed with outstanding results

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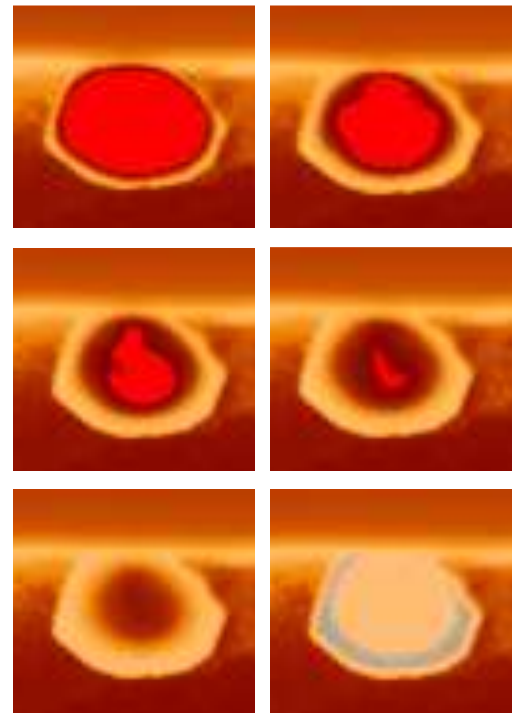
Test chamber for icing mechanisms

Icing of water droplets under
precise conditions, including

- temperatures up to -50°C,
- atmosphere, vacuum or inert gas (N_2)

Observation of freezing process of water droplets on different (coated) surfaces either by optical microscope or by infrared camera

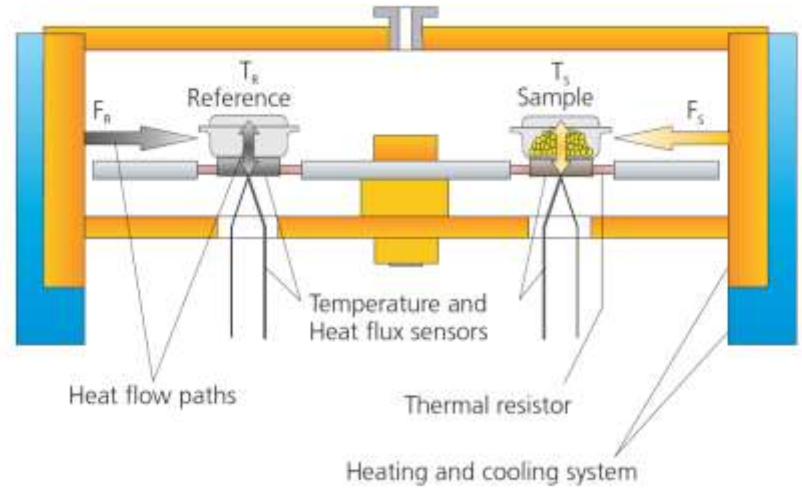


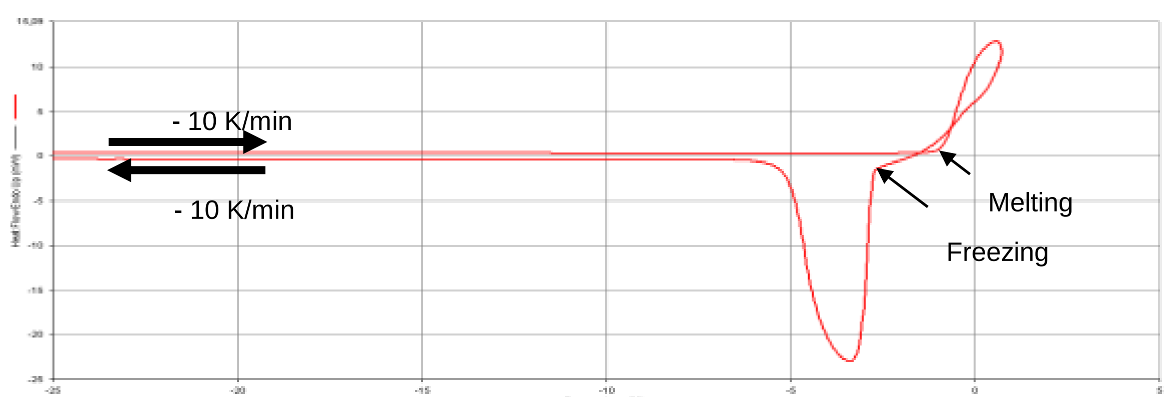
IR-emission of a freezing water droplet

Icing mechanism tests

Dynamic differential calorimetry

Investigations on the freezing point depression caused by functional surfaces





Tests under real conditions

Long-term ice tests on the Mt. Brocken (height: 1141,1m)

Results
- up to now all surfaces with ice formations under these harsh conditions
- ice adherence differs, depending on material

Anti-ice coating concepts

Fraunhofer IFAM works on concepts

prevent or reduce ice formations (Anti-ice)

reduce ice adhesion (improved De-icing)

with emphasis on highlighted methods:

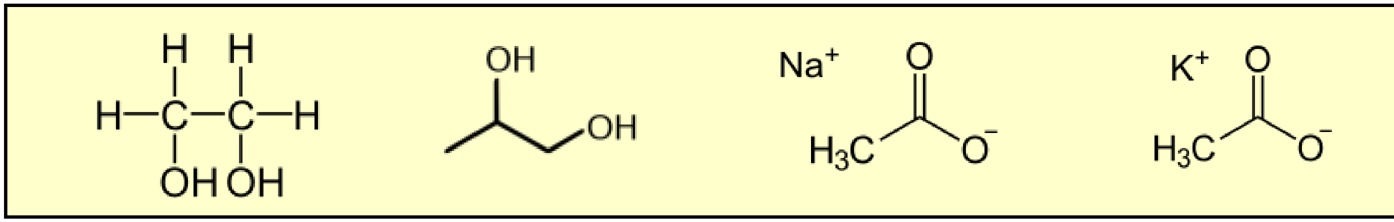
Active methods
Thermal
Chemical
Biochemical
Mechanical
Passive methods
Ice adhesion reduction
Change of wetting behaviour

Active coating concepts

Chemical approach

Use of freezing point depressors that leach out of the organic matrix

Samples:



This approach is only temporary due to leaching effects!

Car wind shields

Temporary Anti-Ice coating for car windshield

Ariane fuel tank

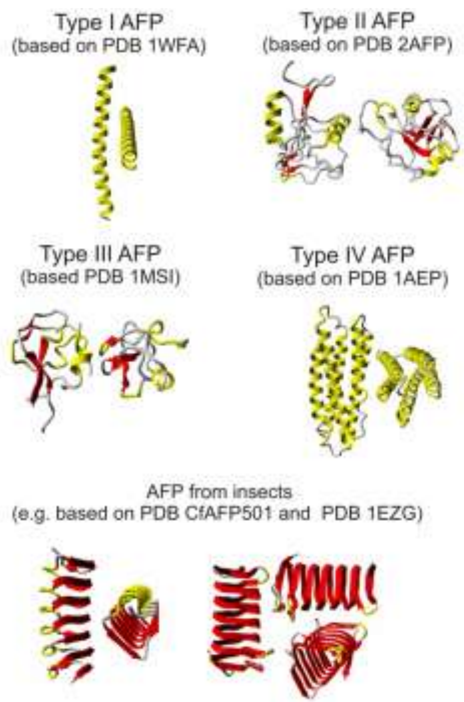
Tests in Cooperation with Astrium and ZARM for support ice removal during take off

Biochemical (biomimetic) approach

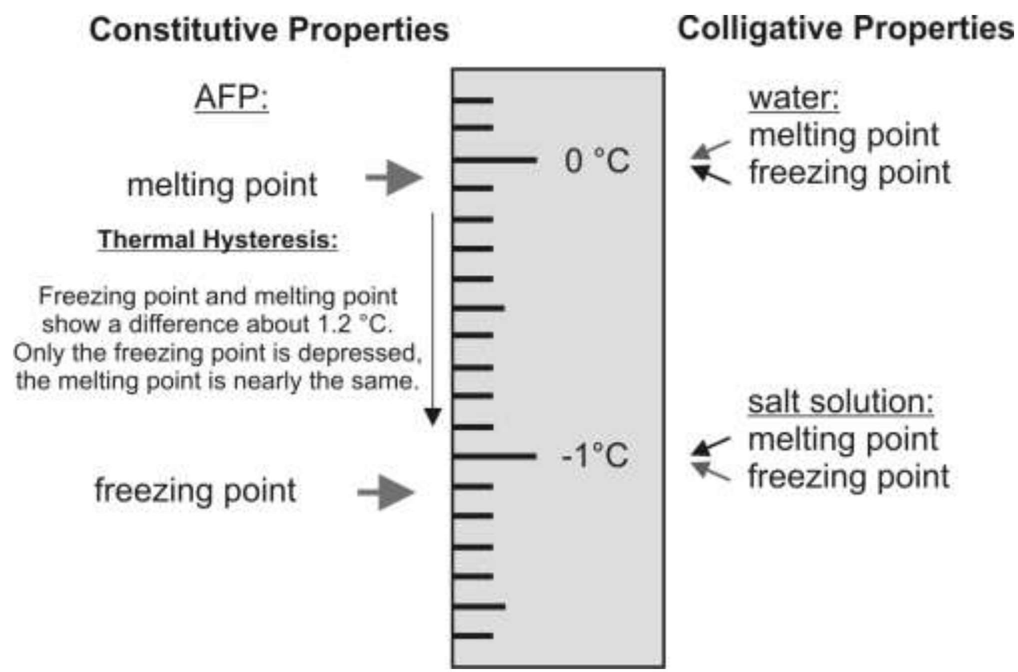
- Anti-freeze proteins (AFP) linked to organic coatings

(Ongoing research project, funded by the Federal Ministry of Education and Research, Germany)

Different types of AFP identified:



Mode of action of AFPs compared to conventional freezing point depressors:



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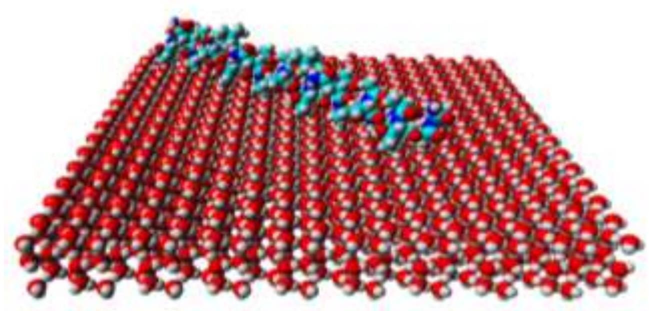
Active coating concepts

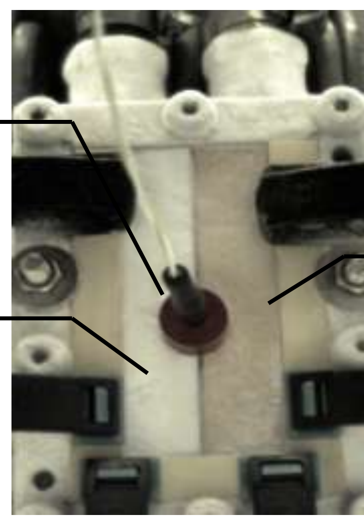
Biochemical (biomimetic) approach



Work performed by Fraunhofer IFAM:

- relevant protein sequences were synthesized
- most promising strategy identified: covalent linkage with use of additional linker molecules

- First promising results with reduced rime ice formation in IFAM ice chamber tests:



Ice adhesion reduction and wetting minimisation

Key parameters to be considered:

Types of bonding
- Electrostatic interactions
- hydrogen bonding
- Van-der-Waals interactions

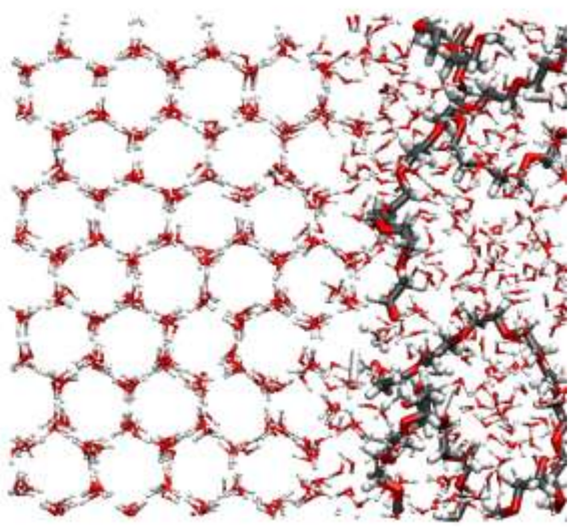
Hydrophobic character
- (super) hydrophobic coatings with reduced wetting behavior
- reduced clear ice

Passive Anti-ice technologies

Surface roughness
- influences hydrophobicity e.g. Lotus effect
- influence ice adhesion

Chemical approach

Further efforts are made within a BMBF funded project in cooperation with IPF (Leibniz-Institute of Polymer Research Dresden, Germany).



In this project the linkage of polymers (PEG) is investigated in terms of anti-icing behaviour, supported by molecular simulation (performed by the group "Applied Surface and Adhesion Science") to predict the influence of functionalized surfaces on the ice nucleation.

Passive coating concepts

Investigations on the influence of key parameters on the icing behaviour of surfaces:

- Optimal balance of hydrophobicity, roughness and available bonding types at the surface were achieved with Fluor- and silicone- modified coatings

Parameter	Unmodified top coat	Passive anti-ice coating
Water contact angle [°]	82	124
Roughness Ra [µm]	0.17 (±0.01)	0.64 (±0.07)
Pictures of the ice rain test		
Description of result	Ice formation after rain at -5°C	• Reduced ice formation due to improved water run-off • Ice adhesion reduced
Limitation	Rime ice accretion is not reduced	

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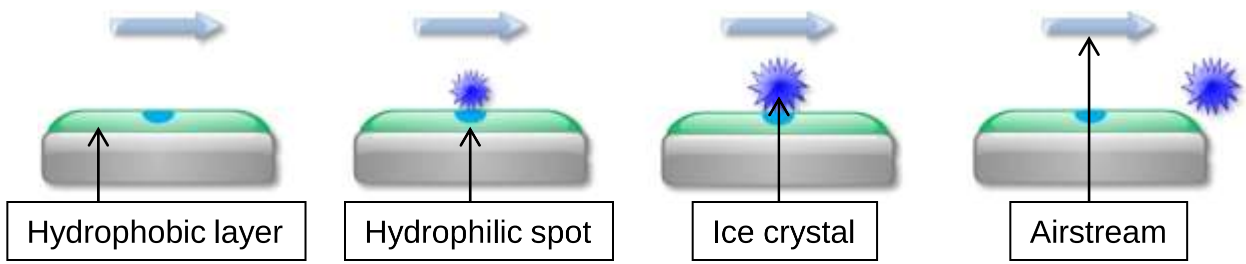
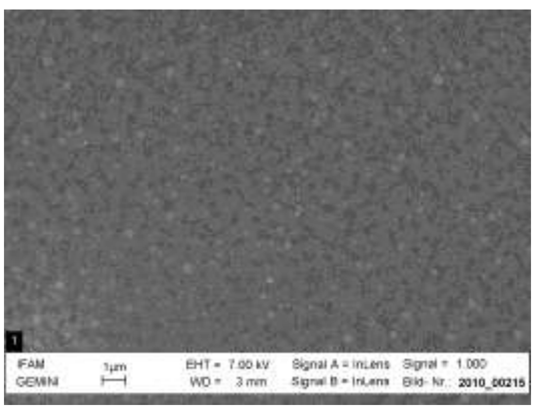
Passive coating concepts

Hydrophobic / hydrophilic structuring

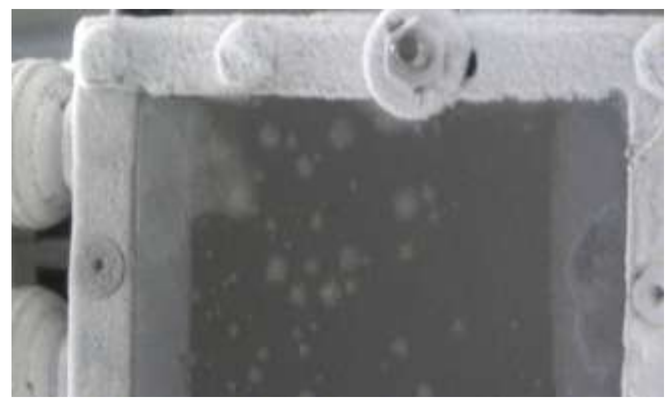
Background: defined hydrophilic anchoring points in a hydrophobic surrounding shall minimise the ice adhesion and hence ease the removal of ice



Use of nano-scaled patterns showed outstanding results, ongoing coating development



SEM picture of coating with nano-scaled Hydrophilic /hydrophobic structuring



Prevention of rime-formation (only partial rime dots)

Outlook

Specialists of Fraunhofer IFAM have gained comprehensive experiences in the development of

anti-ice coatings and
relevant test methods.

This includes the:

- **basic understanding of icing mechanisms**
- **know how in testing of icing behaviour of coatings and surfaces**
- **development of coatings that follow the presented approaches**

<u>Our next steps are:</u>

- **further research on the development of new coating concepts**
- **use of available knowledge to the needs of specific technical applications**
- **studies on further scientific background regarding icing processes**
- **further development of test methods to assure best prediction models**

Thank you!