Effect of icephobic coating on ice protection of ultrasonic anemometer with stack-type transducers

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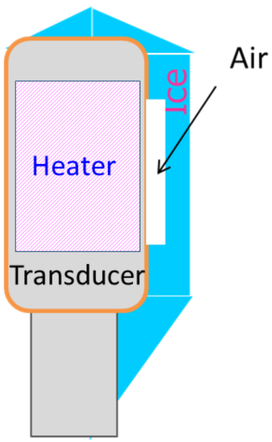
Background

- ✓ Erroneous data transmission from heated ultrasonic wind sensor with stack-type transducers in winter, in a snowfall environment

- ✓ The possible cause of measurement errors was found out by repeatedly carrying out the snowing, at-room-temperature and subzero wind tunnel tests



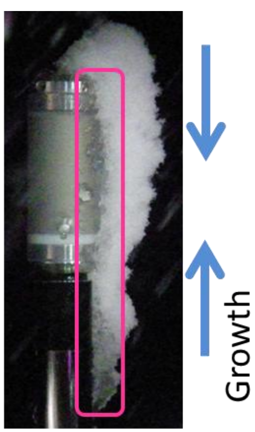
  - ➢ Ice-Bridge formation due to the secondary icing
  - ➢ An air gap between the heated transducer surface and the ice deposit
  - ➢ in order to prevent the transducers from the ice-bridge formation,

⇩

Background

Scenario

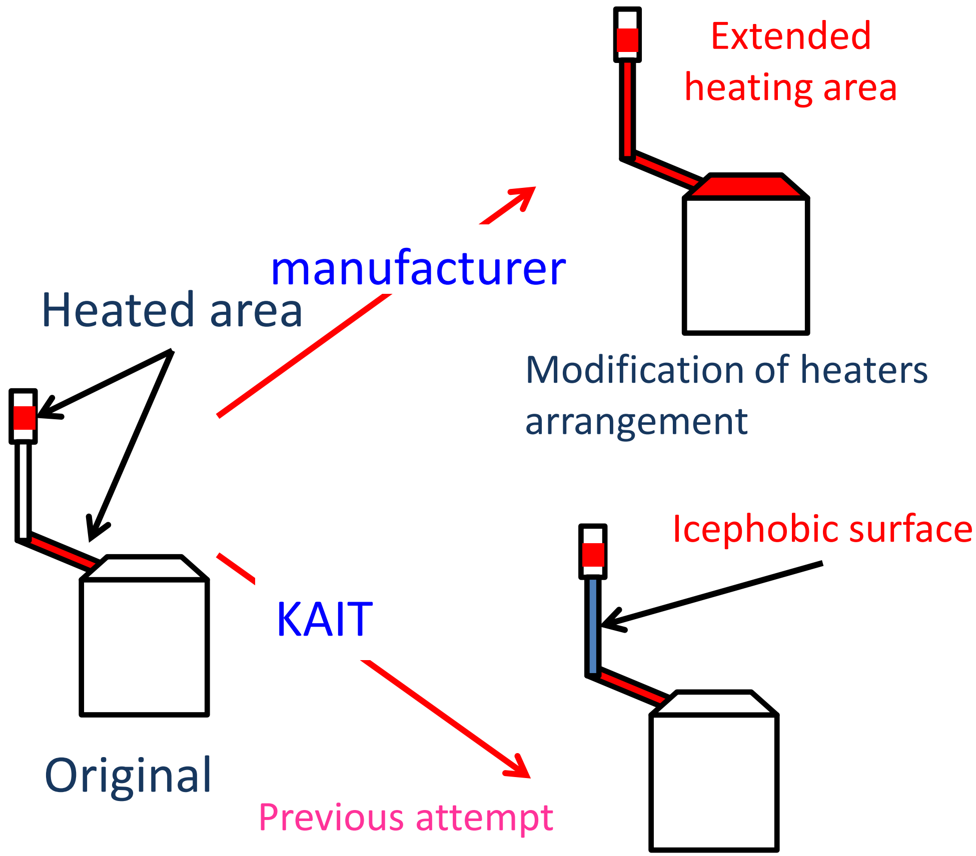
- Snow accretes
- Melted by heat
- Meltwater runs down to unheated area
- Secondary icing occurs
  - Ice grows from the upper and lower side
- Ice-Bridge forms



Secondary icing

Secondary icing:
See IEC61400 New/Modified version

A physical phenomenon of icing process of Ice/snow accretion-meltwater(due to heat)-refreezing

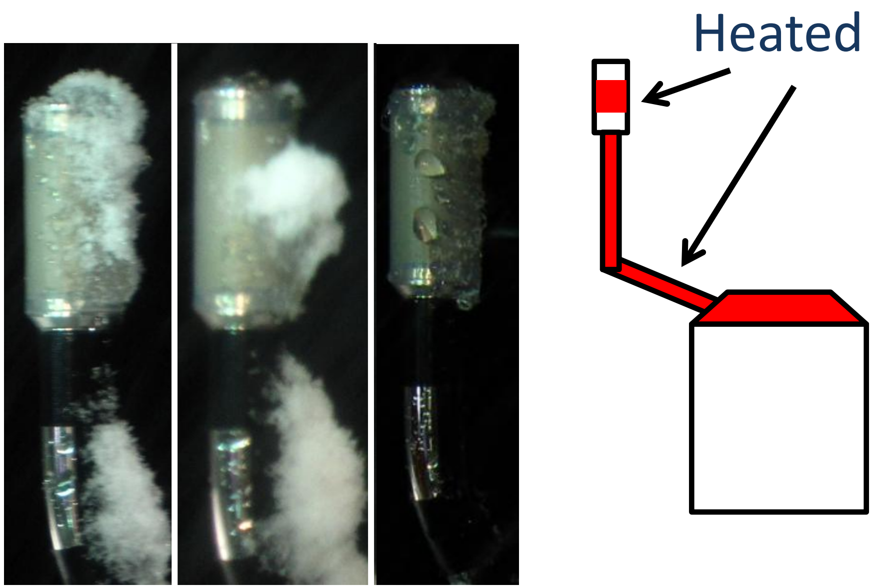


Modification of heaters arrangement

Application of superhydrophobic coating (NTT-AT HIREC-100)

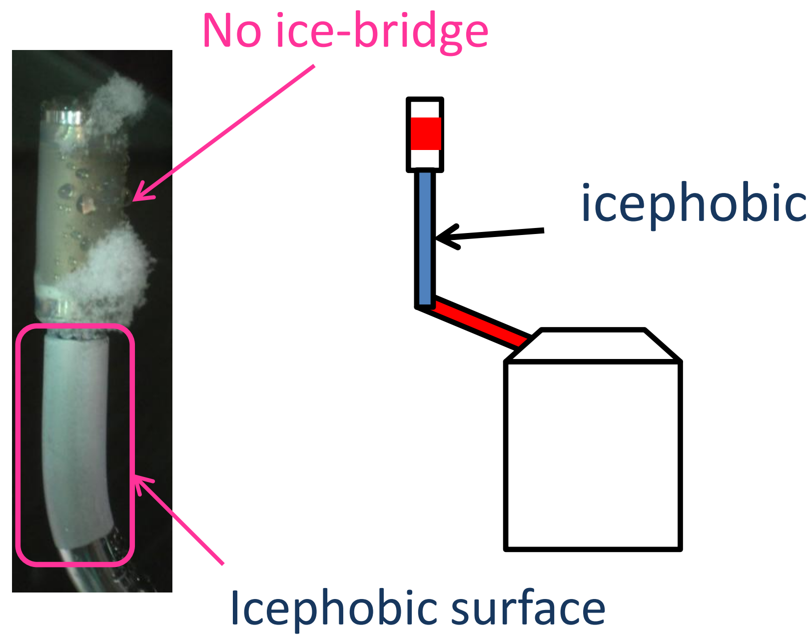
Results from previous snowing tests

Modified model



- No rigid ice-bridge formation due to slight snow/ice accretion on the upper arm surface
- Smaller amount of snow

Partly coated model

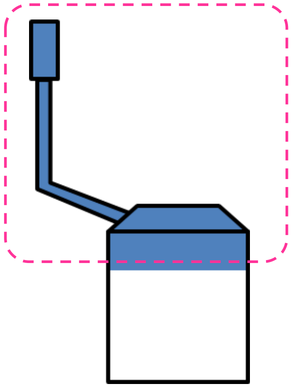


- No ice-bridge formation due to no ice accretion on the upper arm surface
- Smaller amount of snow on the transducer surface

Objectives

Practical application of superhydrophobic coating, we have been focusing

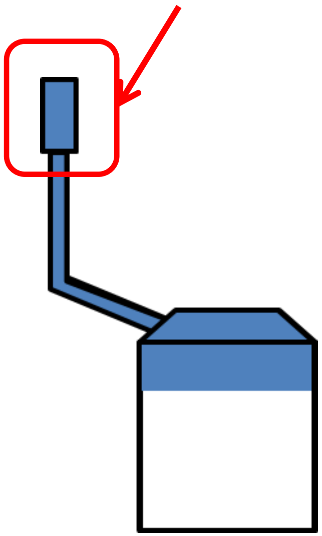
- To confirm the applicability of the off-the-shelf superhydrophhobic paint to the ultrasonic anemometer with the stack-type transducers
  - No influences on the wind measurement by the presence of a film on the transducer surface?
  - No chemical damage to the transducer?

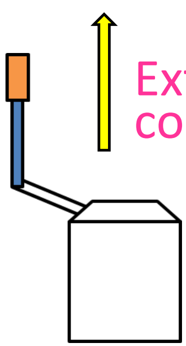


- To examine whether the coated (extended coated area) anemometer works or not, by carrying out the *snowing* wind tunnel test

Flow of the present reserch

Coating on transducer surface





Extension of coated area

Previous attempt

- Damage to measurement due to the presence of a thin membrane
  - ✓ Examination of the transmissivity by impedance analysis
  - ✓ by the wind tunnel test with an imitated membrane covering of vinyl chloride at room temperature
  - ✓ By the wind tunnel test at room temperature after coating process

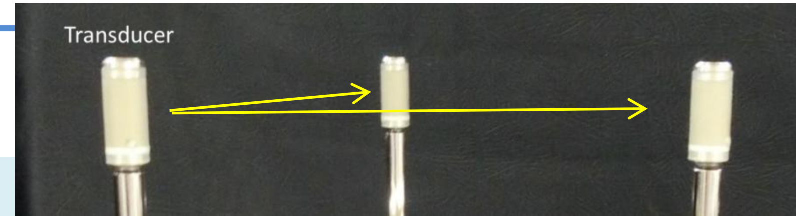
- Chemical damage of the paint thinner to the silicon covering

  ⇨ by the immersion test

  ⇩ If it's OK, then

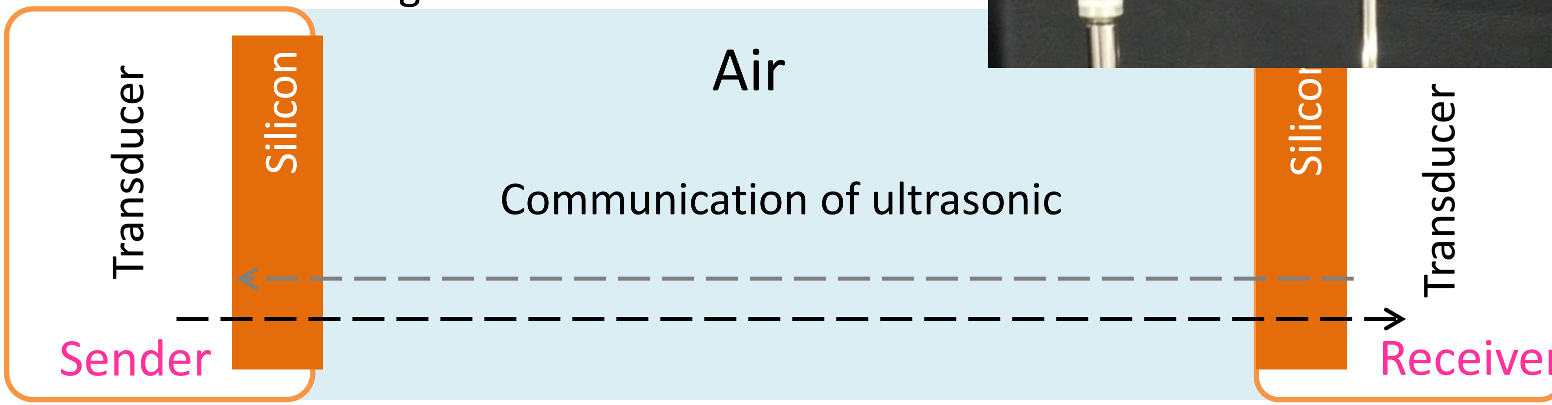
Snowing wind tunnel

Acoustic propagation



Normal measurement

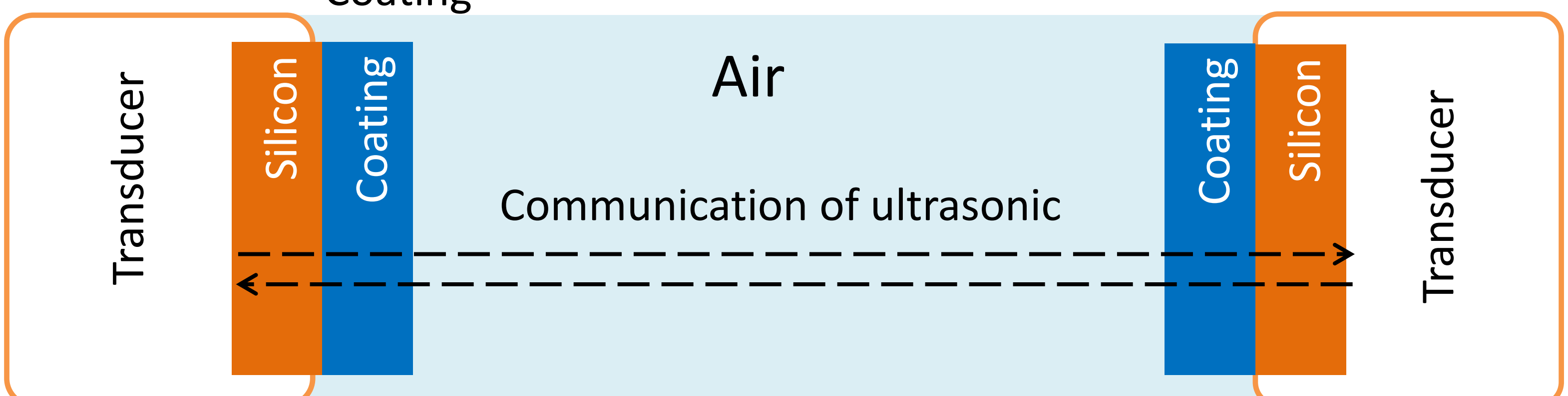
Silicon covering



Silicon ⇒ Air ⇒ Silicon

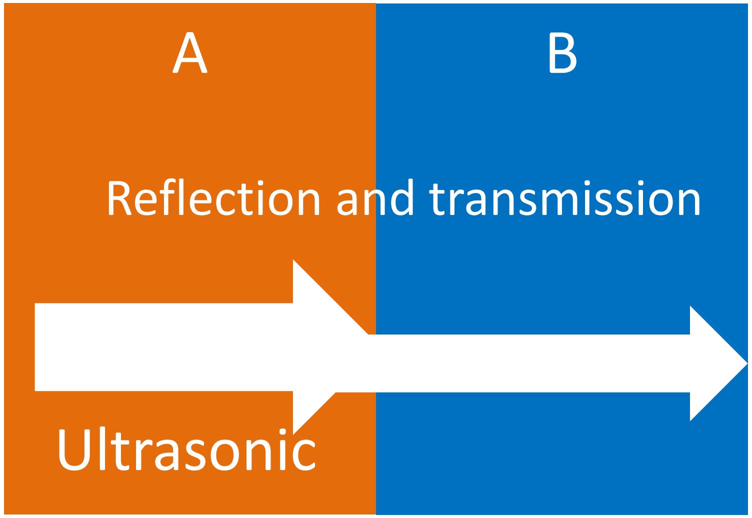
Coated

Coating



Silicon ⇨ Coating ⇨ Air ⇨ Coating ⇨ Silicon

Acoustic impedance & transmissivity



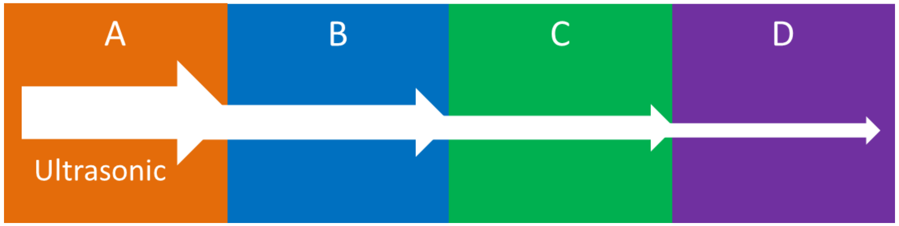
When ultrasonic waves penetrate into the medium B from A, reflection and transmission take place in accordance with the impedance of A & B.

The acoustic tranmissivity is the ratio of the transmitted to the incident sound pressure at the interface of the media.

Acoustic transmissivity: t

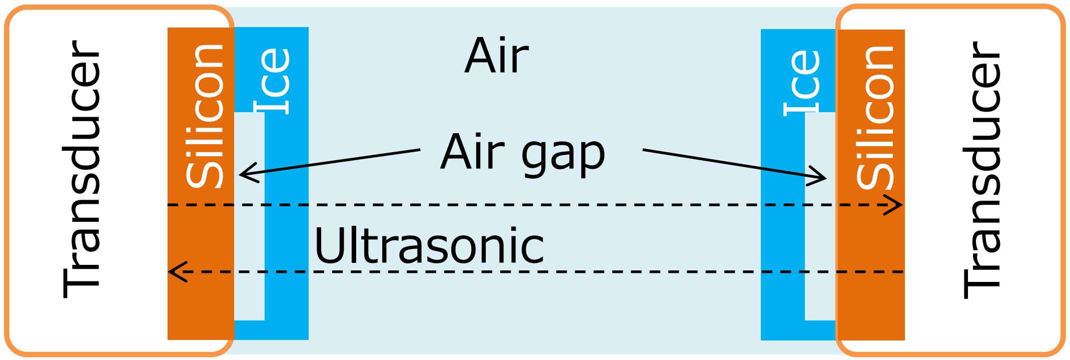
$$t = \frac{2Z_B}{Z_A + Z_B}$$

Acoustic impedance : $Z_{A,}$ Z_B [Ns/m^3]



$$t = t_{AB} \times t_{BC} \times t_{CD}$$

Acoustic transmissivity – Ice-bridge case



Silicon-Air-Ice-Air-Ice-Air-Silicon

Ice-bridge with an air gap at the interface

Conceivable cases

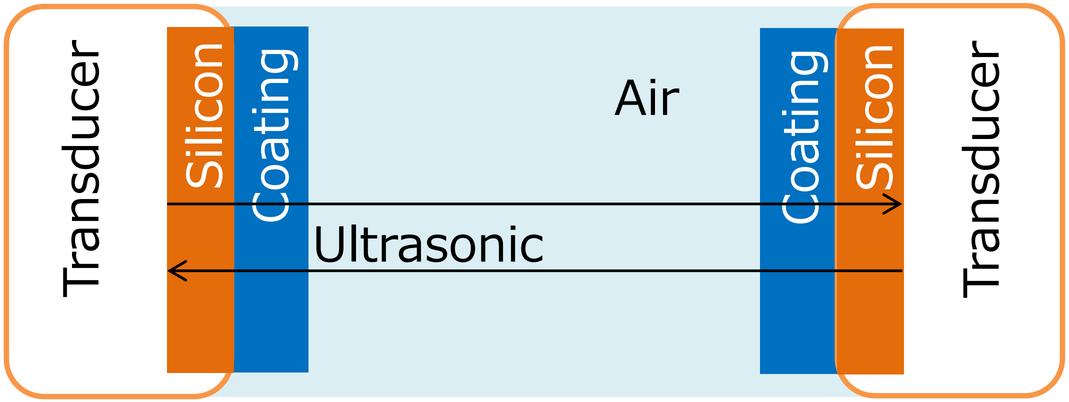
Conditions of transducer stack	Combination of media	Transmission coefficient
Ice free	S-A-S	1.10e-03
Iced/ Iced + gap	S-I-A-S	1.96e-04
	S-I-A-I-S	3.92e-04
	S-A-I-A-I-S	5.16e-07
	S-A-I-A-I-A-S	2.41e-10
Coated	S-C-A-C-S	1.54e-03
	S-C-I-A-I-C-S	3.50e-04

No more correct wind measurement

the order of magnitude of -7 to -10

S	Silicon
I	Ice
A	Air
C	Coating film

Acoustic transmissivity - Summary



S	Silicon
I	Ice
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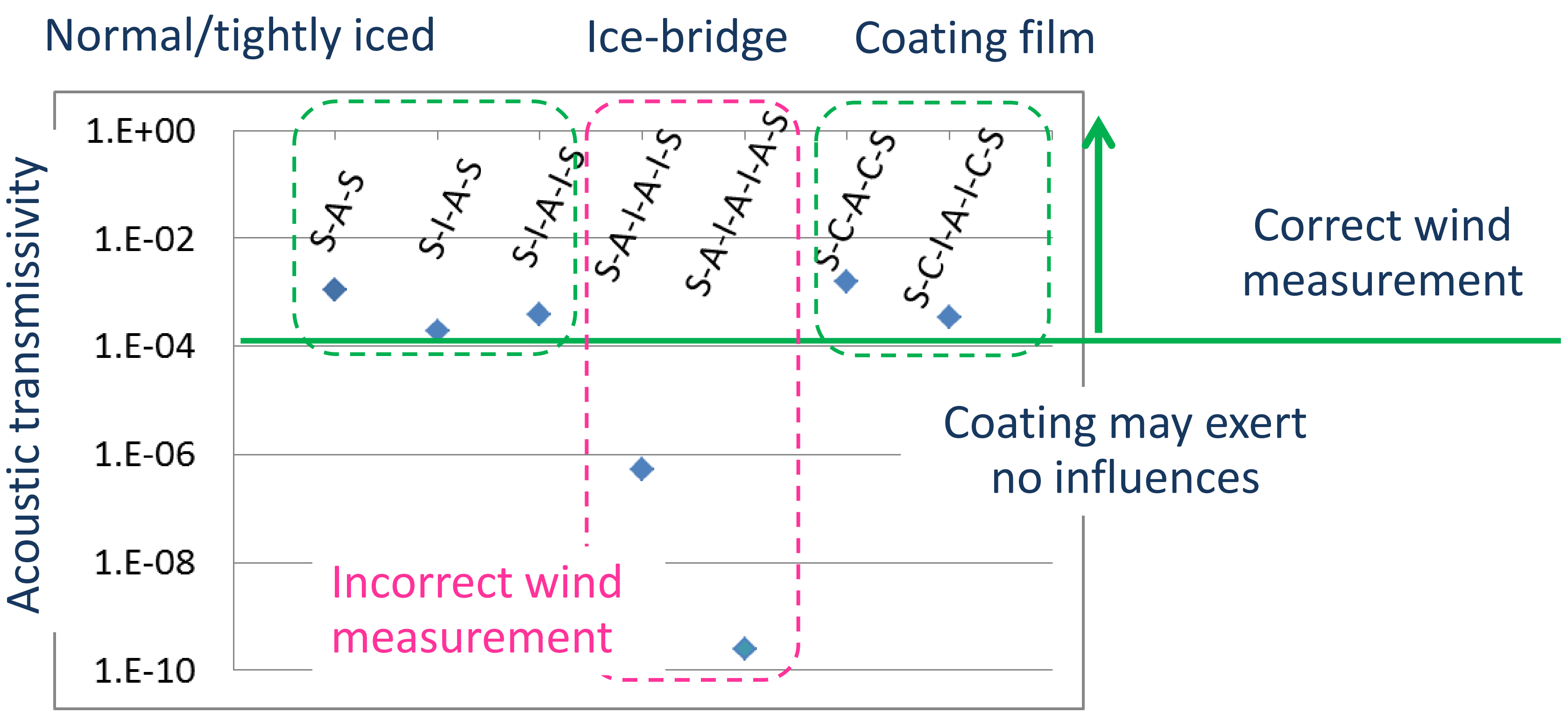
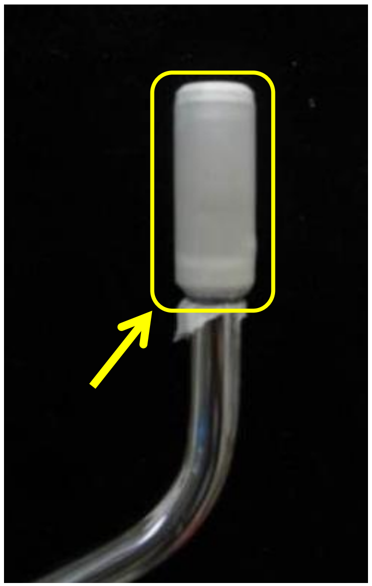
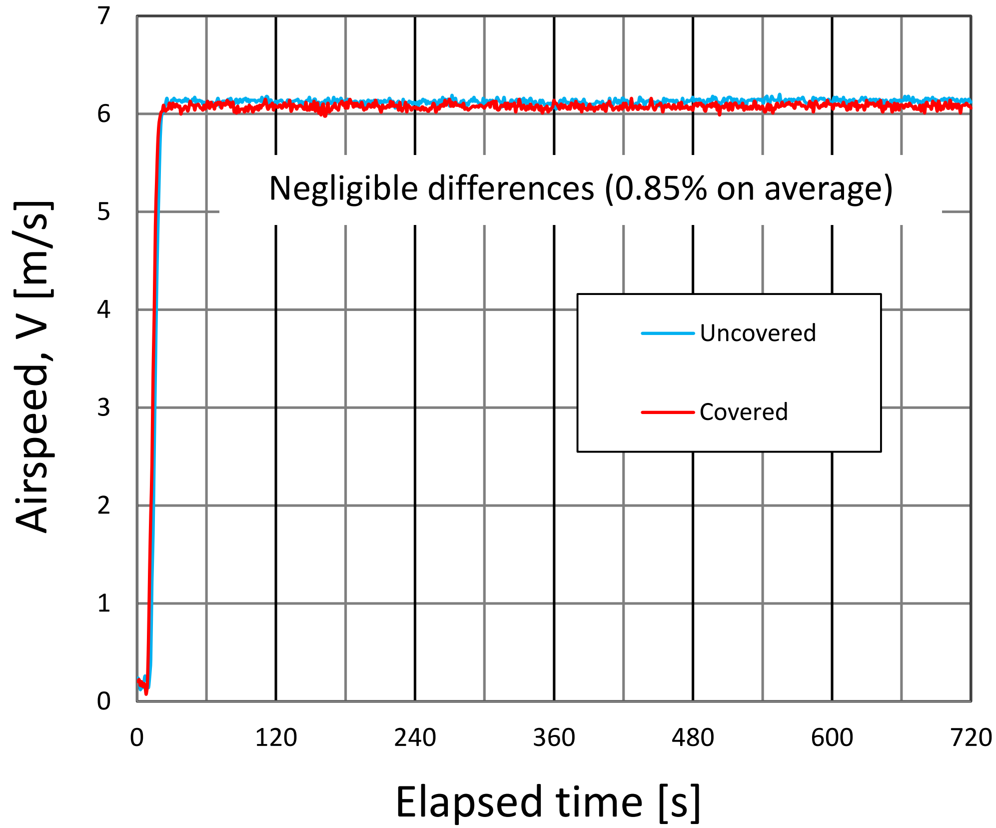


Wind tunnel test – with membrane covering

To evaluate the effect of the presence of the membrane on the transducer surface on wind measurement



Imitated coating by a membrane covering of vinyl chloride
(similar acoustic impedance value of the paint)



Expectation of applicability of coating to the transducers

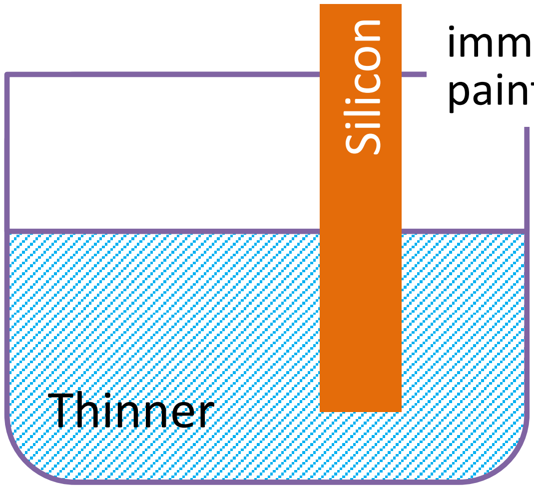
Immersion test

in coating process : Paint + Thinner

Damage by chemical agent?

(for 21days)

taken off from
the real anemometer



immersed into the
paint thinner

JIS k 5600-1
(ISO 2812-1)

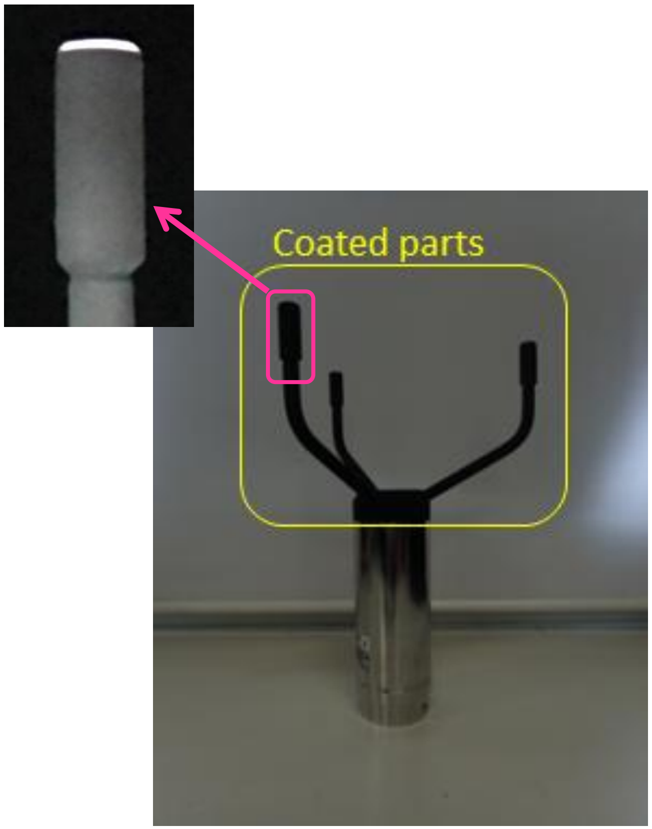
Paint thinner: Butyl acetate

No chemical damage

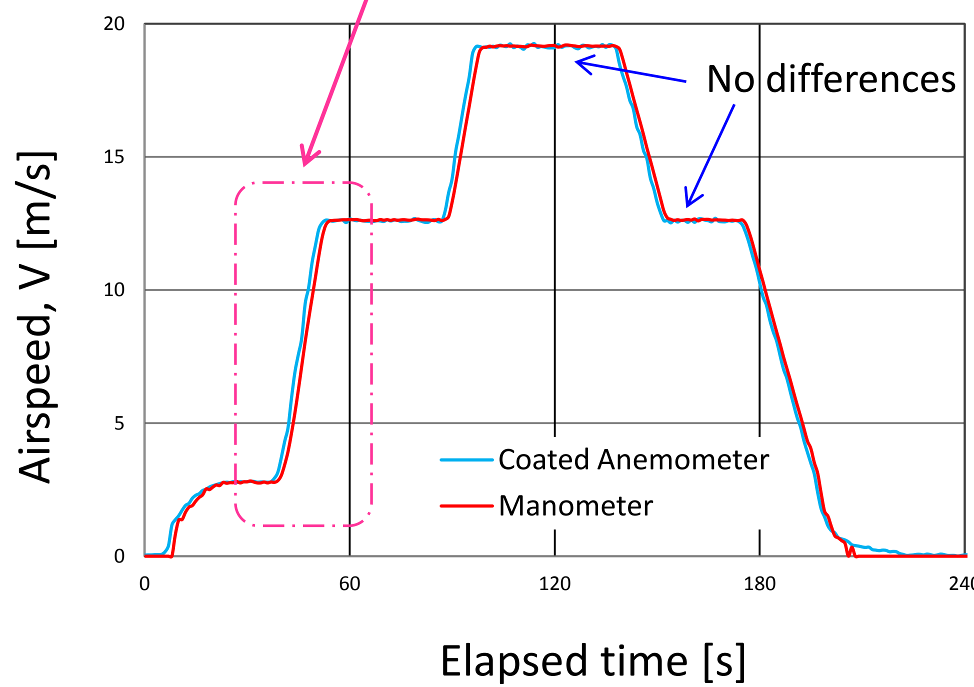
Applicability of the paint to the transducers

Validation of correct wind measurement

To examine the performance of the coated ultrasonic anemometer by the wind tunnel test with changing the airspeed at room temperature



The coated ultrasonic anemometer responds to the change of the airspeed in the wind tunnel more quickly than the Pitot-manometer system

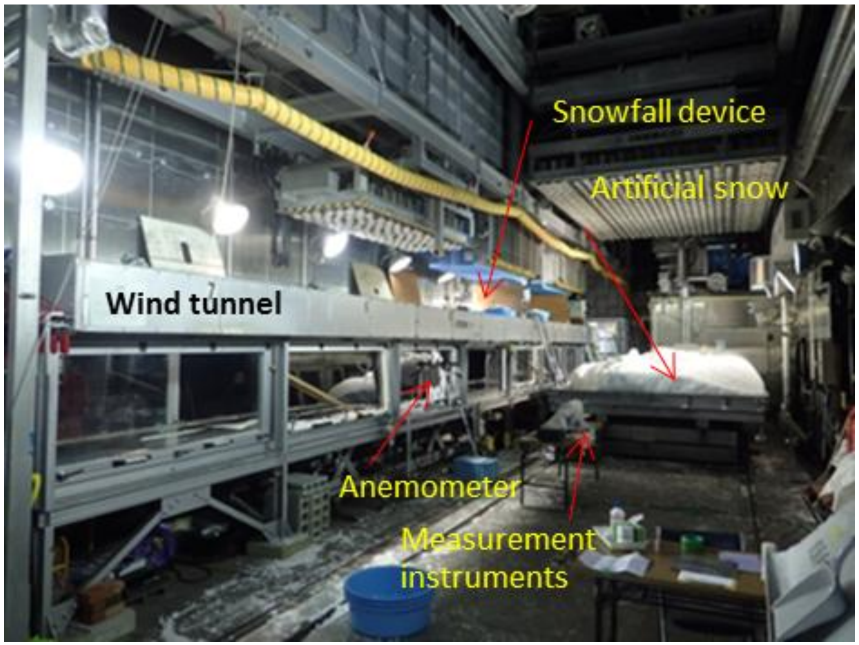


The coated ultrasonic anemometer works

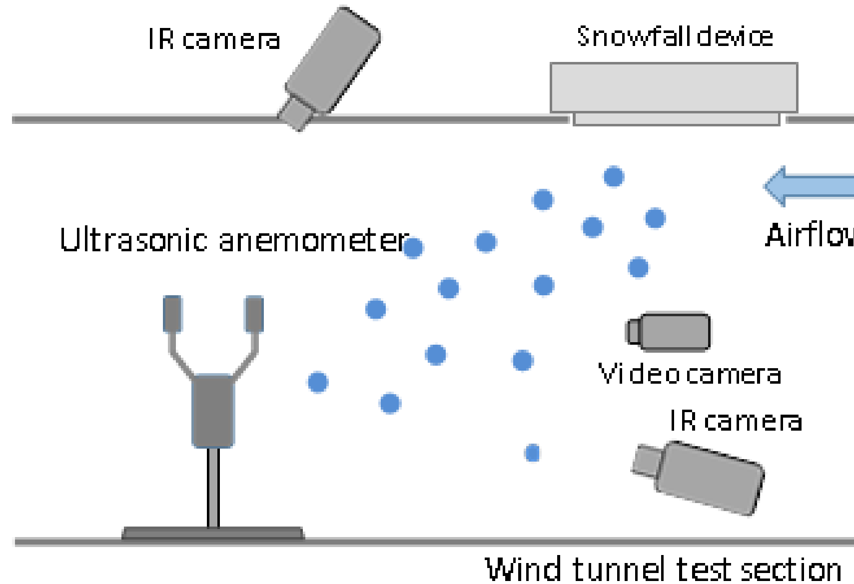
not for snow/ice protection

Snowing wind tunnel test

Wind tunnel in the Cryospheric Environment Simulator



At Shinjo CES Laboratory,
National Research Institute for Earth Science and Disaster Prevention



Schematic of snowing wind tunnel test

Ultrasonic anemometers:

- Original (limited heating)
- Modified by the manufacturer
- Coated original

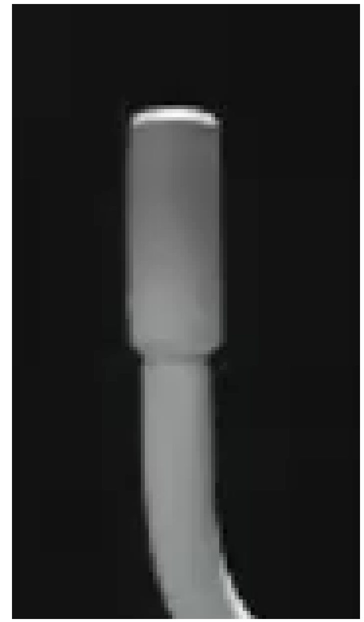
Coating: NTT-AT HIREC100

Snowing test – 1 m/s

How snow accumulates on the transducer or snow turns to ice

same model

Original model

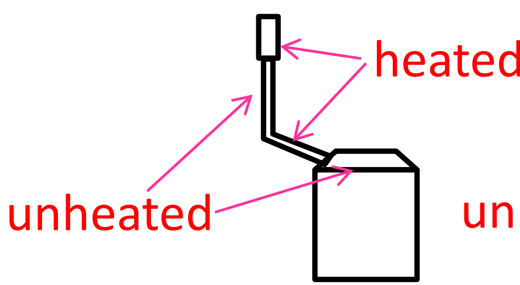


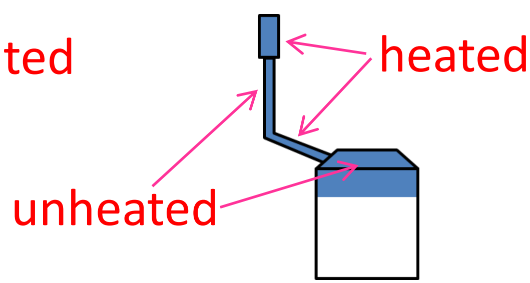
Superhydrophobically coated model

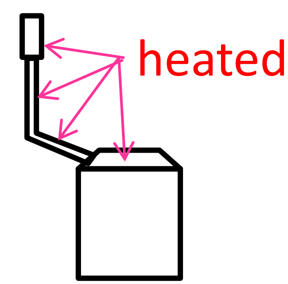
Modified model

Test conditions

Wind speed: 1 m/s
Amb. Temp.: -12 degC
Duration: 20 min







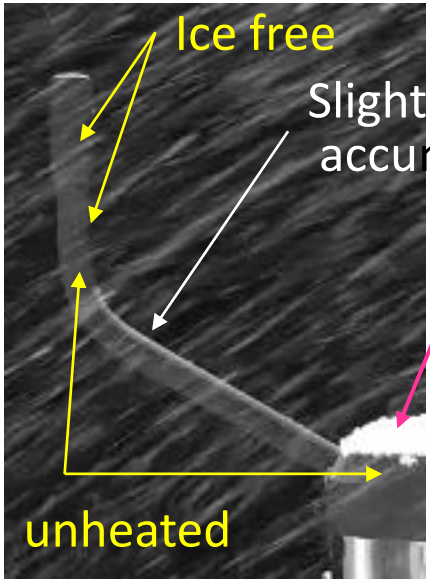
You are watching the same video repeatedly

Snowing test – 1 m/s

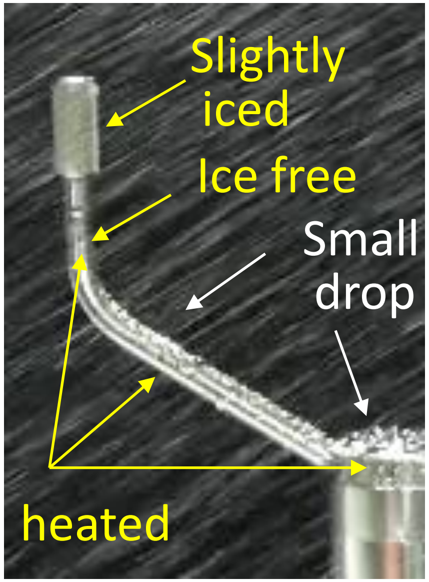
Test conditions

Wind speed: 1m/s
Amb. Temp.: -12 degC
Duration: 20 min

Coated model



Modified model



- Ice-free surface (except the top cover) was kept during the test run
- Snow accumulated on the top cover of the body

- The transducer surface was slightly iced due to the secondary icing
- No snow/ice accretion occurred on the arms and the top cover.

You are watching the same video repeatedly

Snowing test – 1 m/s

Original model

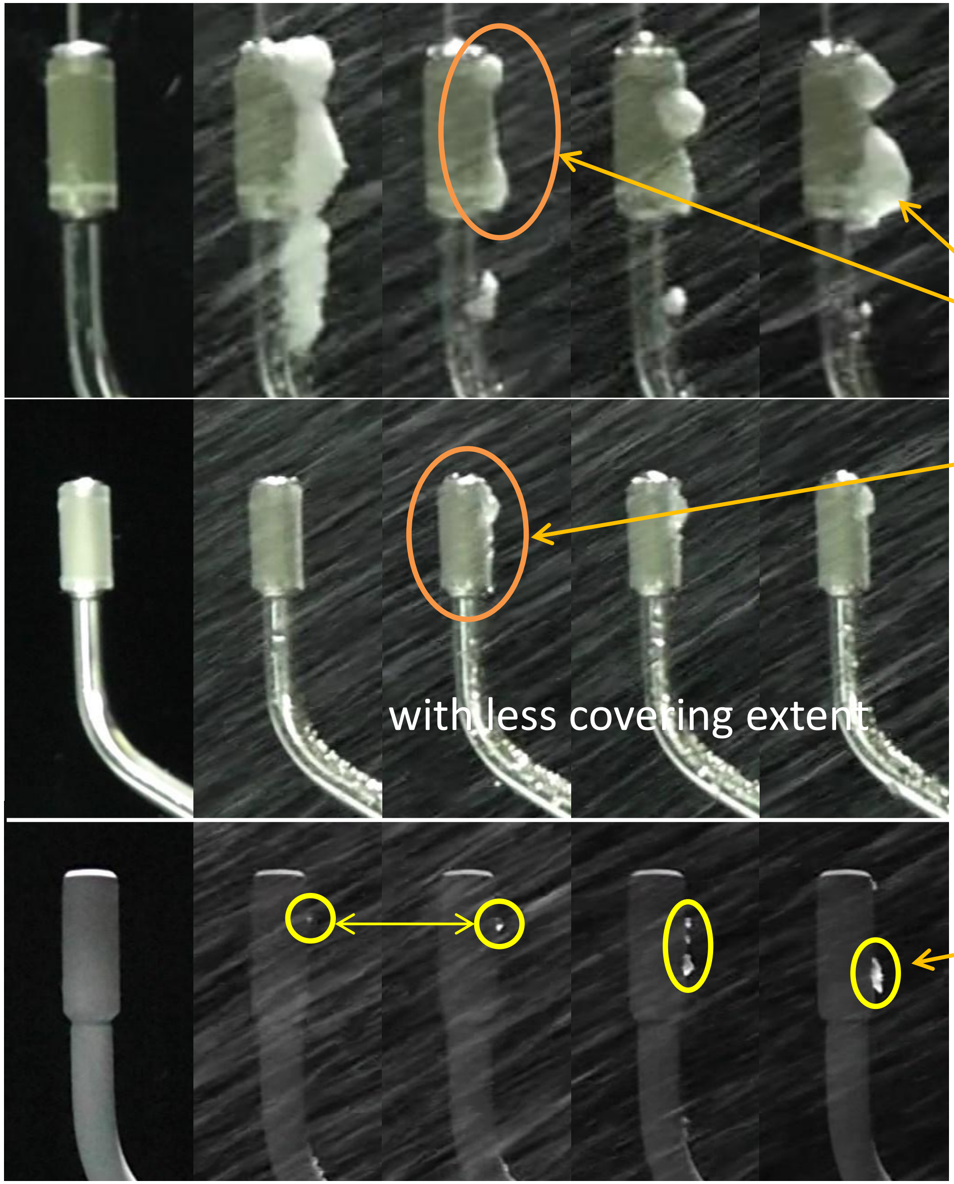
Snow flux:
3.50g/m^2s

Modified model

Snow flux:
4.46g/m^2s

Coated model

Snow flux:
4.19g/m^2s

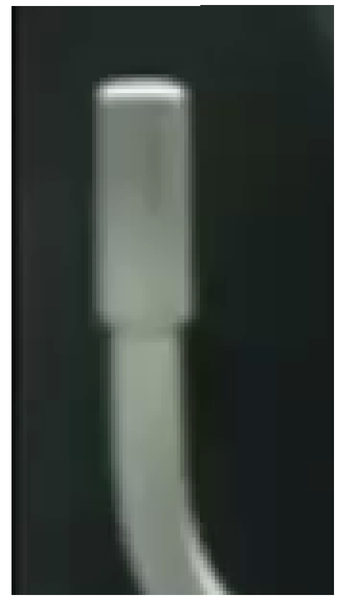


Snowing test – 6 m/s

How snow accumulates on the transducer or snow turns to ice

same model

Original model

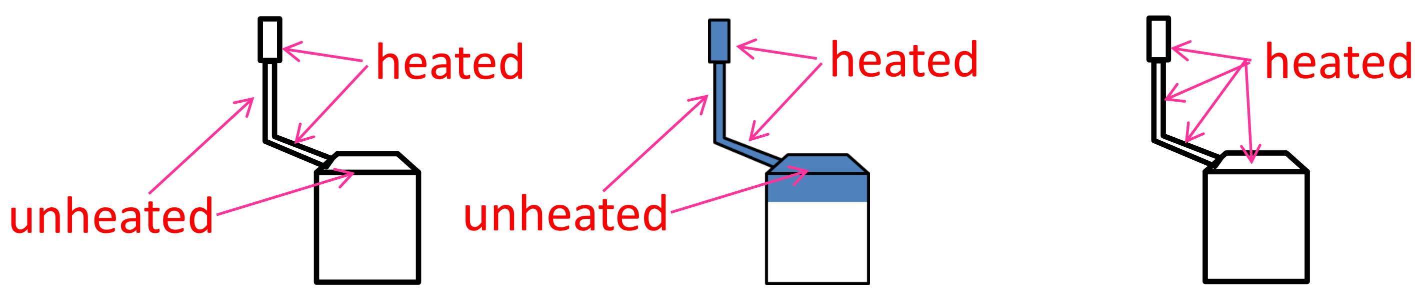


Superhydrophobically coated model

Modified model

Test conditions

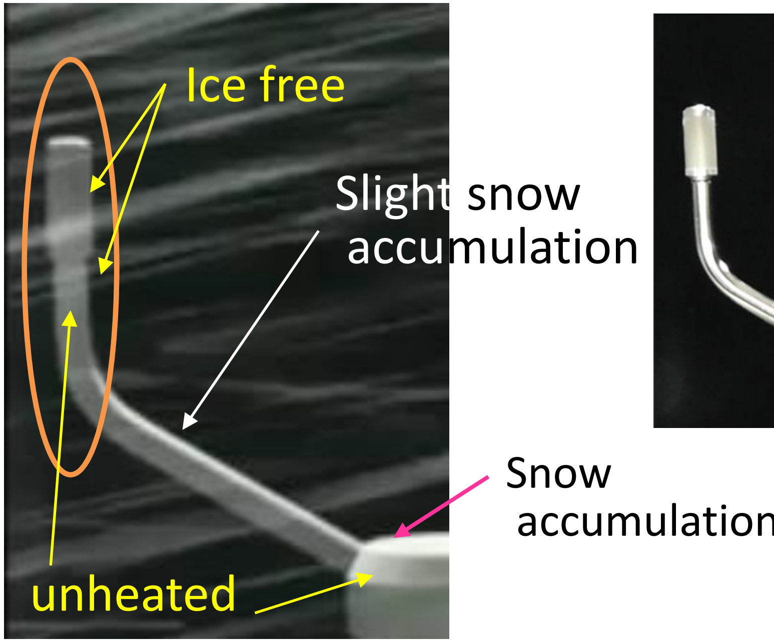
Wind speed: 6m/s
Amb. Temp.: -12 degC
Duration: 20 min



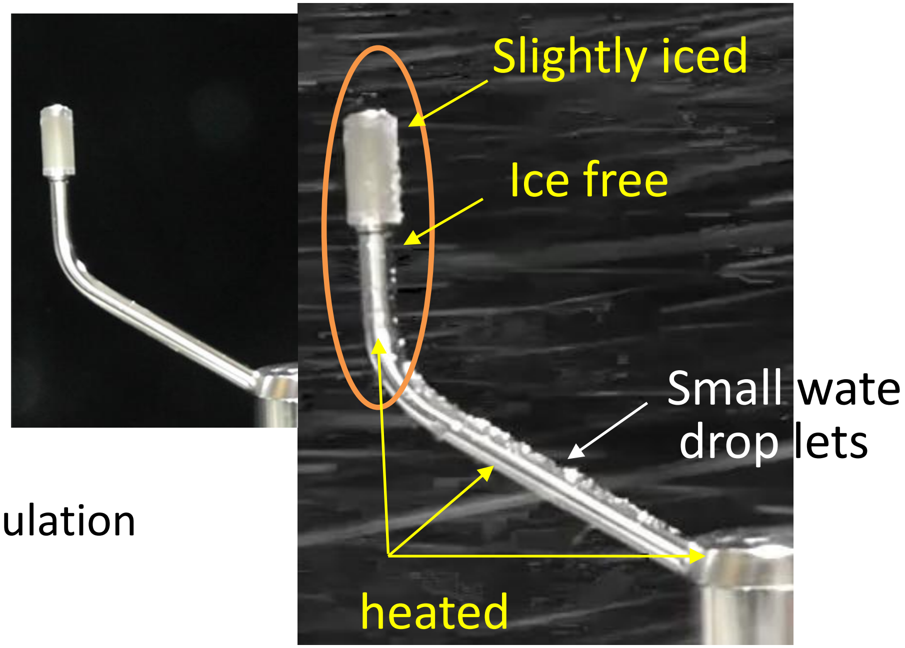
Snowing test – 6 m/s

Test conditions
Wind speed: 6m/s
Amb. Temp.: -12 degC
Duration: 20 min

Coated model



Modified model



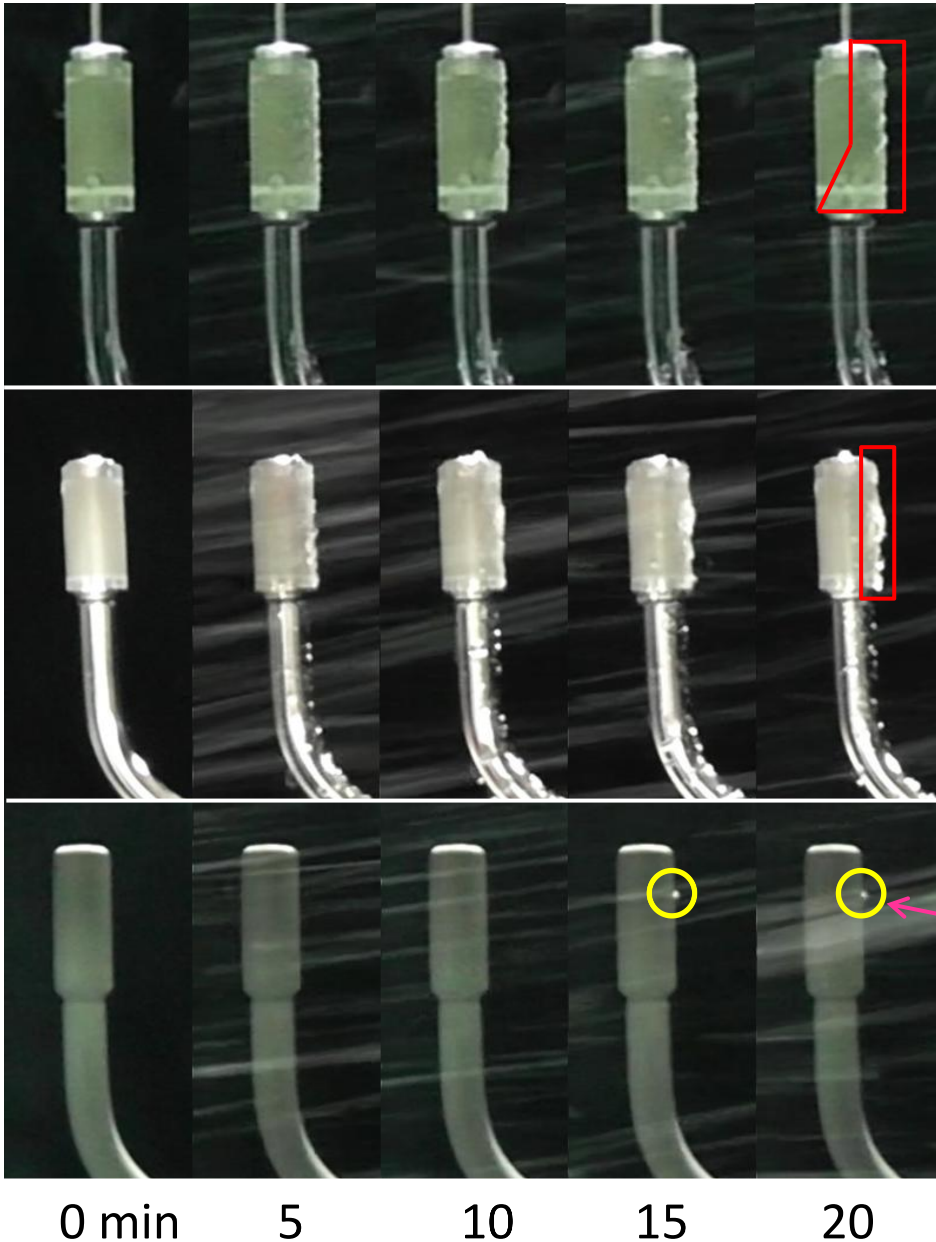
- Ice-free surface kept during the test run
- No ice deposit remained on the transducer & arm surface
- Snow didn't accumulate on the top cover due to the higher wind speed

- No ice bridge was made on the transducer
- Meltwater stayed on the arm surface but not froze
- No snow accumulation on the top cover was found

✓ Coating and modification work quite well for ice/snow protection

You are watching the same video repeatedly

Snowing test – 6 m/s



Original model

Snow flux: 3.55g/m²s

- No snow accretion & Secondary icing events occurred
- But no influences on measurement were exerted

After 90° -rotation, ice affected measurement

Modified model

Snow flux: 3.85g/m²s

- No snow accretion & Slight secondary icing events occurred
- But no influences on measurement were exerted

Coated model

Snow flux: 3.56g/m²s

Minute ice deposit formed

No icing occurred on the coated surfaces throughout the test run

Concluding remarks

- ✓ The performance of a superhydrophobic coating for ice protection of the ultrasonic anemometer with the stack-type transducers was examined by carrying out the snowing wind tunnel test.
- ✓ Prior to the wind tunnel test, an acoustic impedance analysis for the acoustic tranmissivity, an immersion test, and the additional wind tunnel tests at room temperature were implemented.
  - The impedance analysis indicated that the coating film would exert no negative effect (the transmissivity at the same level as the ice free case) on the wind measurement.
  - From the wind tunnel tests, it was found that the presence of the thin membrane on the transducer surface exerted no influences on the measurement.
- ✓ The snowing wind tunnel test indicated that no ice/snow accretion occurred on the superhydrophobically coated surfaces of the ultra-sonic anemometer at the wind speed of 1 and 6 m/s.
- ✓ The superhydrophobic coating may work well for ice protection in snowfall environments.

How it works under icing conditions?

Thank you
for your kind attention

Tack så mycket