New resistivity control method for carbon sputtering for fast production

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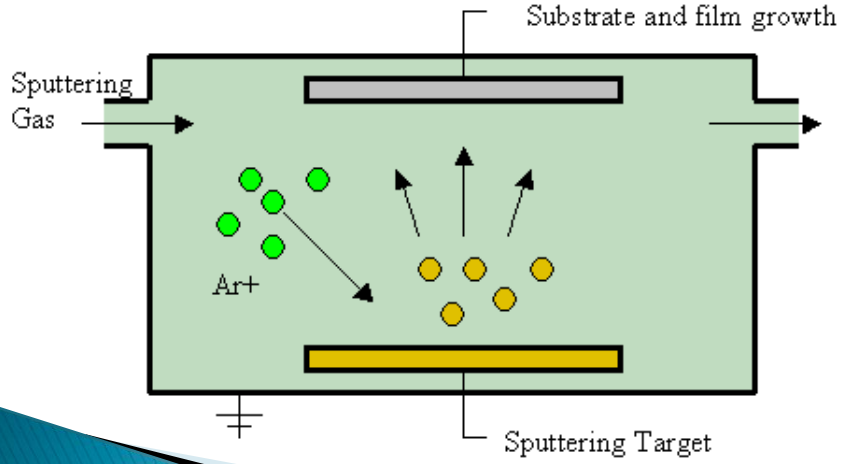
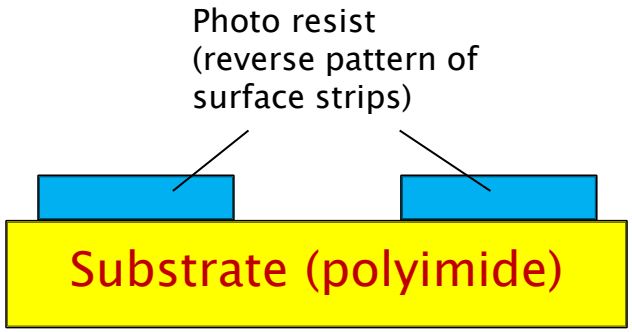
Liftoff process using sputtering

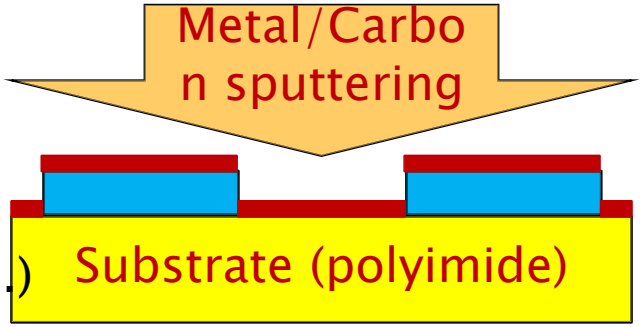
- Very fine structure (a few tens micro meter) can be formed using photo resist. (same as PCB)
- Surface resistivity can be controlled by sputtering material and their thickness



@PCB company (Laytech inc.)



@Sputtering company (Be-Sputter inc.)

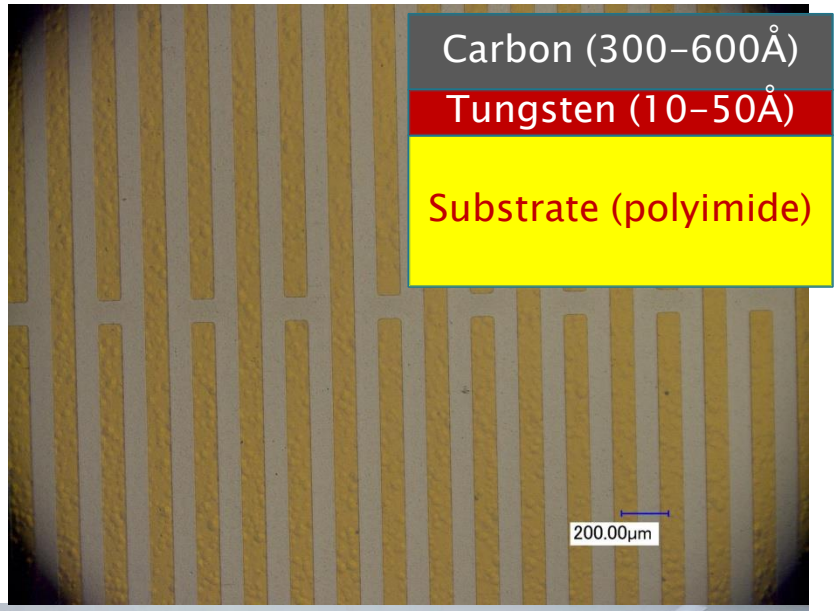


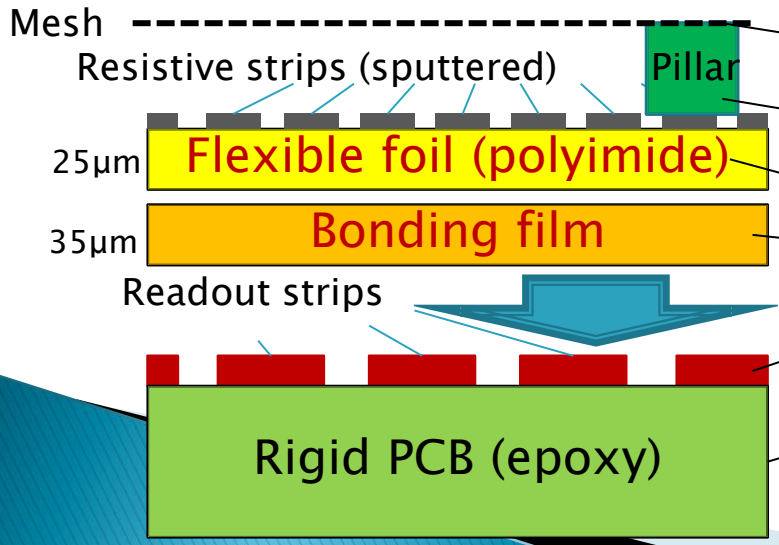
Developing the resists

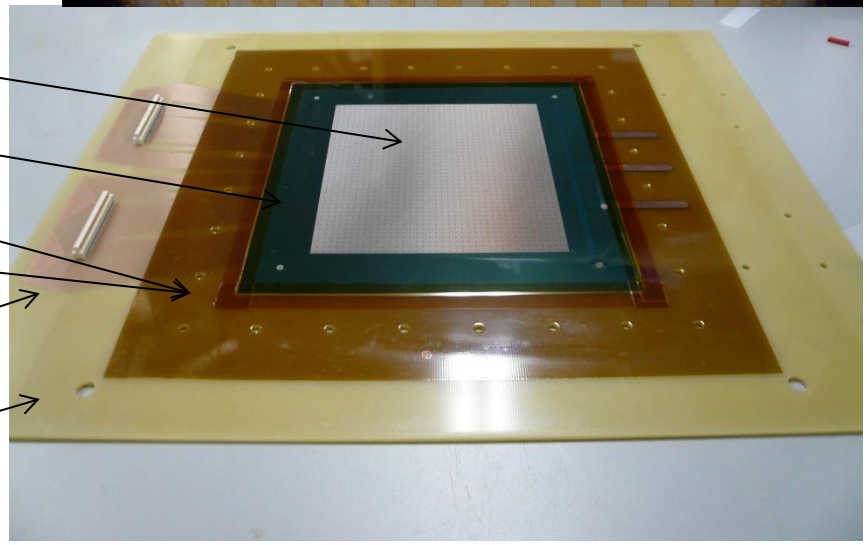
@PCB company (Laytech inc.)

Prototype of small MicroMEGAS

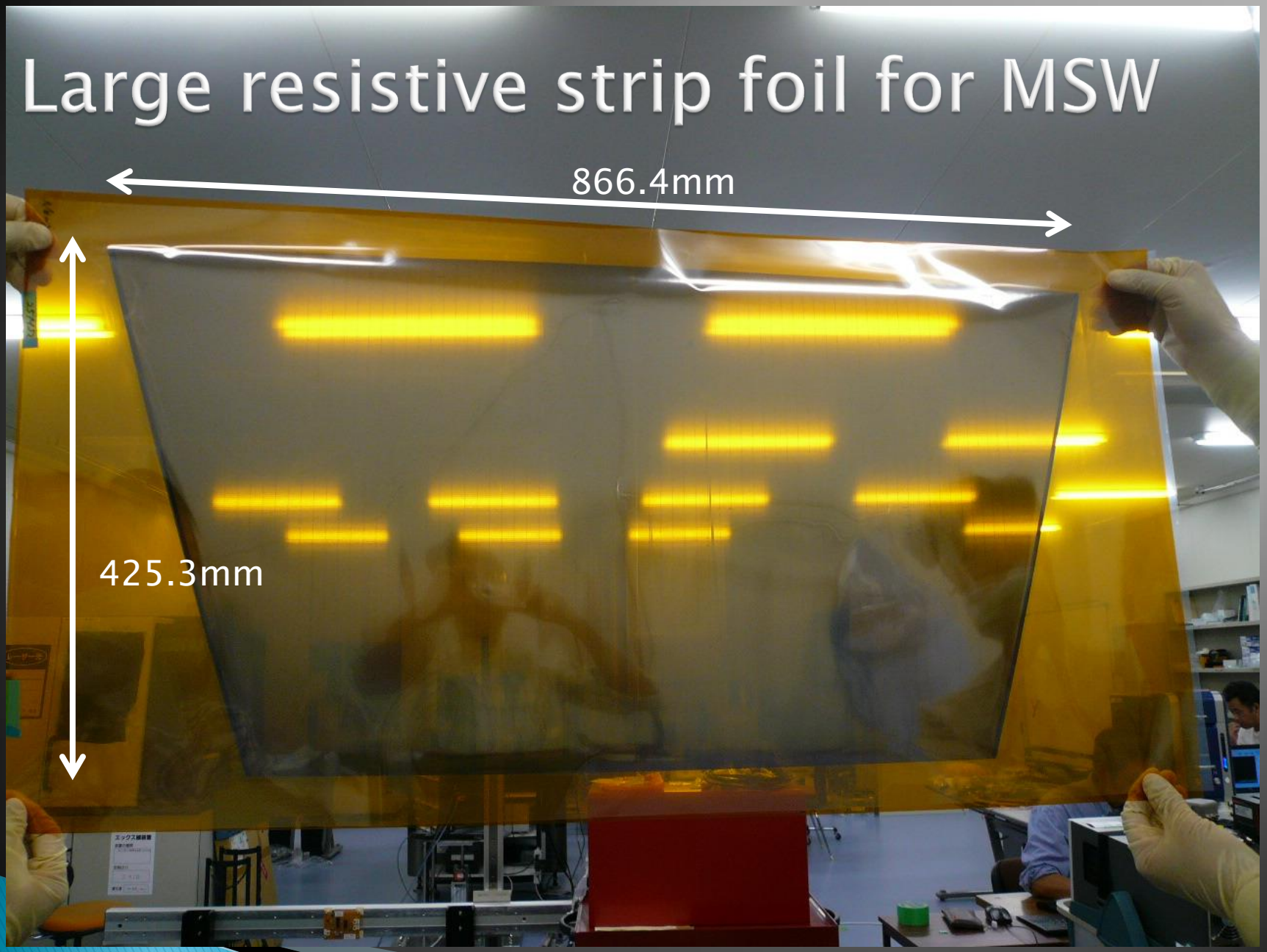
- June, 2013 – bulk MM
  - Surface resistivity: 10MΩ/sq.
    - With 300Å carbon + 50Å W
- November, 2013 – floating mesh
  - Surface resistivity: 500kΩ/sq.
    - With 3600Å carbon
- The readout board consists of
    - Readout strips (Rigid PCB).
    - Resistive strip foil (Polyimide film).
  - Fine strip pitch of 200 μm is formed on 25μm polyimide foil.
  - Substrate thickness : 60 μm.



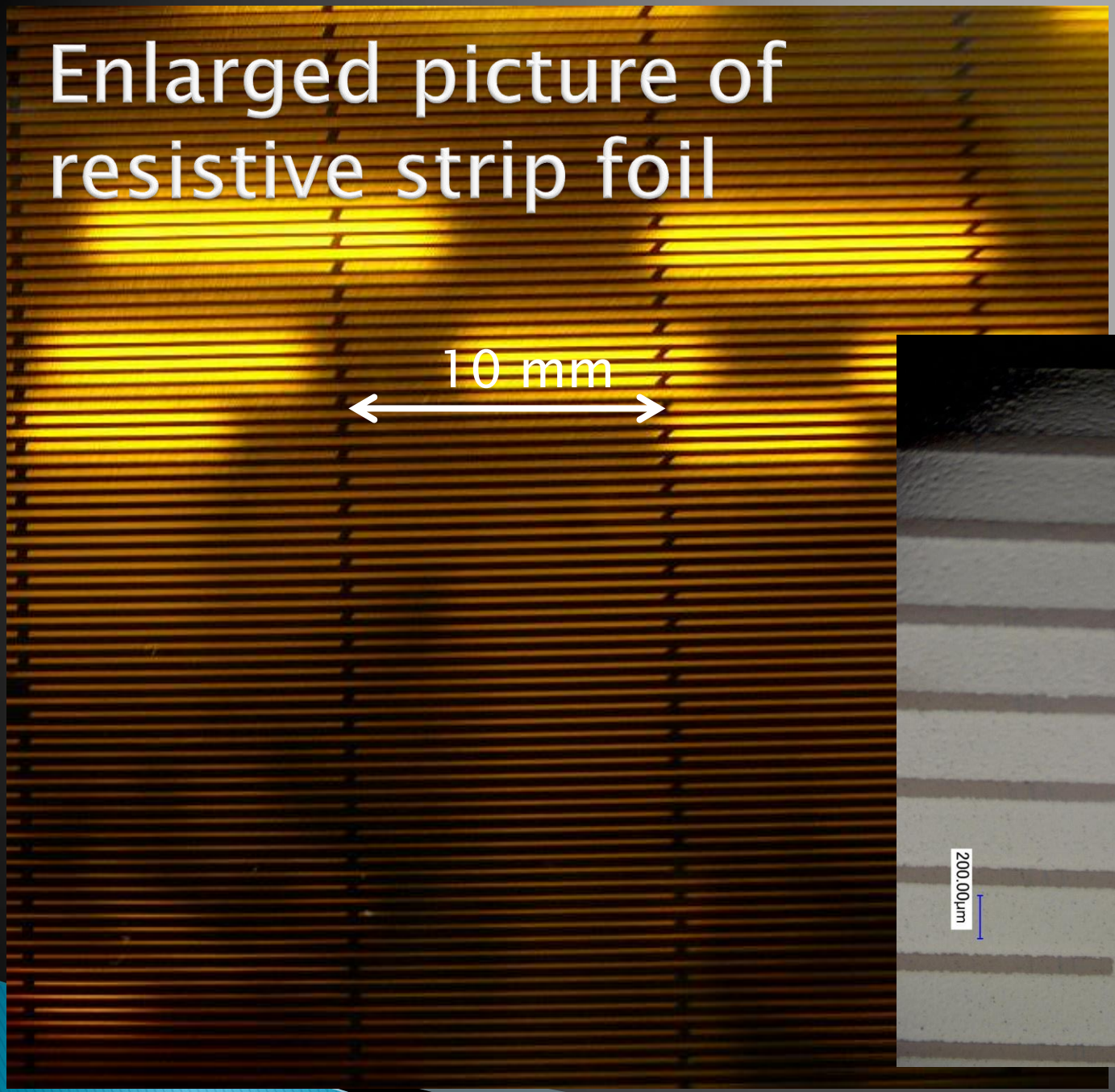




Large resistive strip foil for MSW



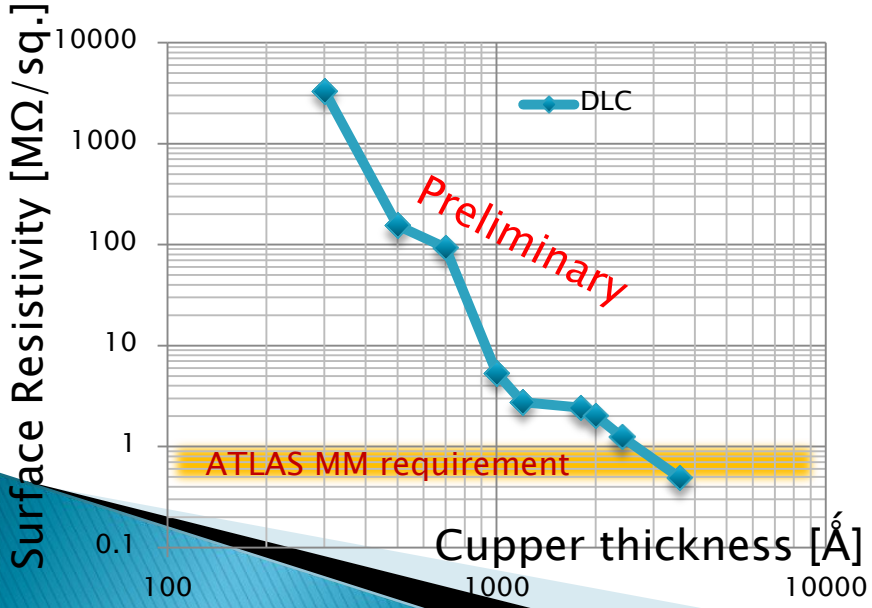
Enlarged picture of resistive strip foil

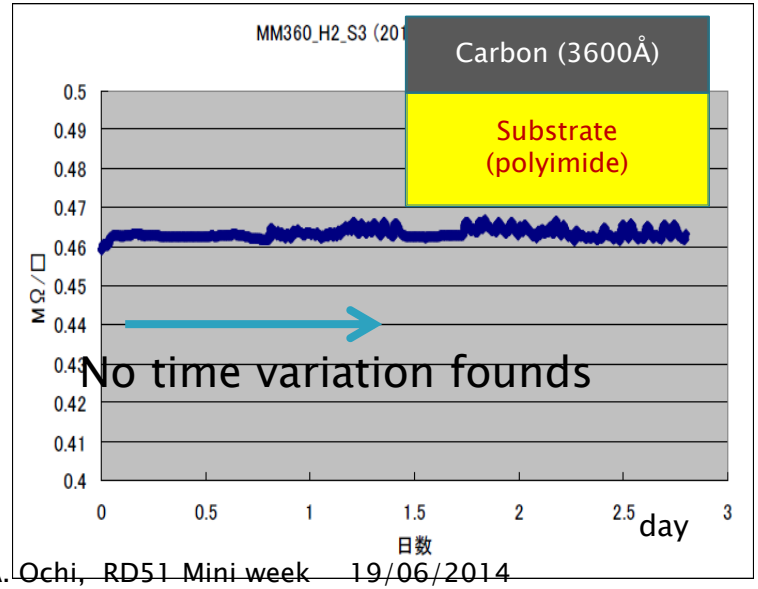


Resistivity and it's stability

- Resistivity dependence on carbon thickness
  - 300Å → 2GΩ/sq.
  - 3600Å → 500kΩ/sq.
  - Conductivity is not proportional to the thickness (t < 1000Å)
  - At t > 1000Å, good reproducibility found
- No time variation founds after several days from sputtering

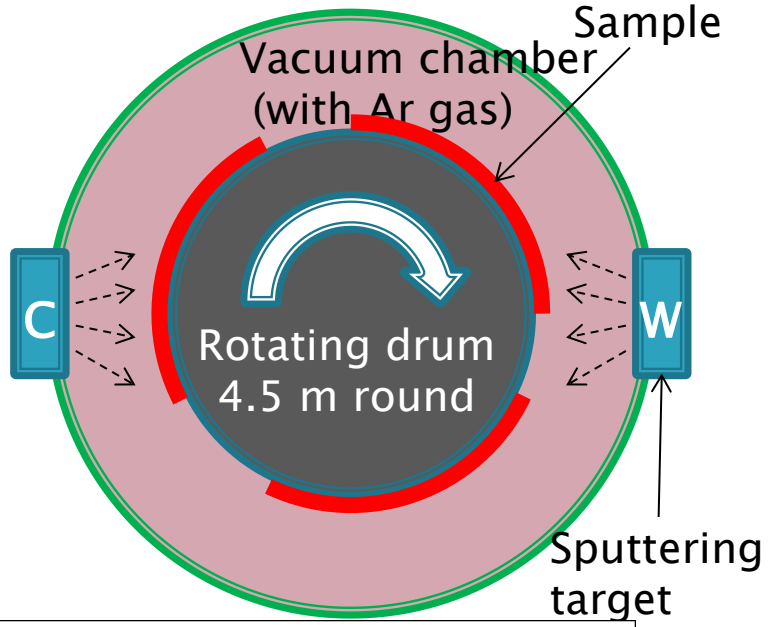
- However, deposition rate is very slow.
  - 500-600Å / hours are maximum rate in industrial chamber.
  - For ATLAS MM, 3600Å = 6hours are needed!!
  - The MSW foils were made by this longtime sputtering.
  - But we need faster way for mass production.

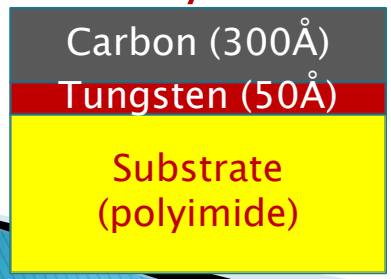


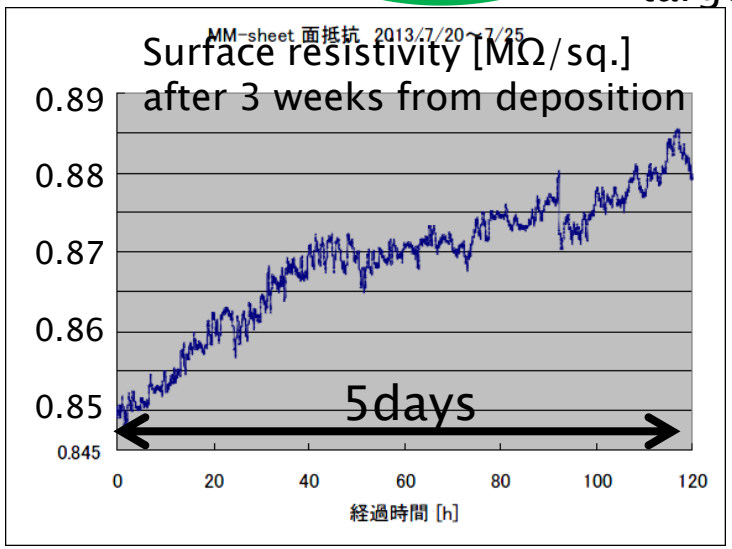


First trial … Carbon with metal

- The sputtering chamber (in Be-Sputter Co. Ltd,) has two target stations.
  - Different target can be equipped, e.g. Carbon + Metal
  - At the first time, we have tried the Carbon and Tungsten target.
  - W 50Å + C 300Å shows low resistivity (<1MΩ/sq.) with short (~ 30 min.) sputtering time.
  - However, the resistivity is not stable, due to the oxidation of the metal.
- It is not good way for using (thin) metal to control the resistivity.

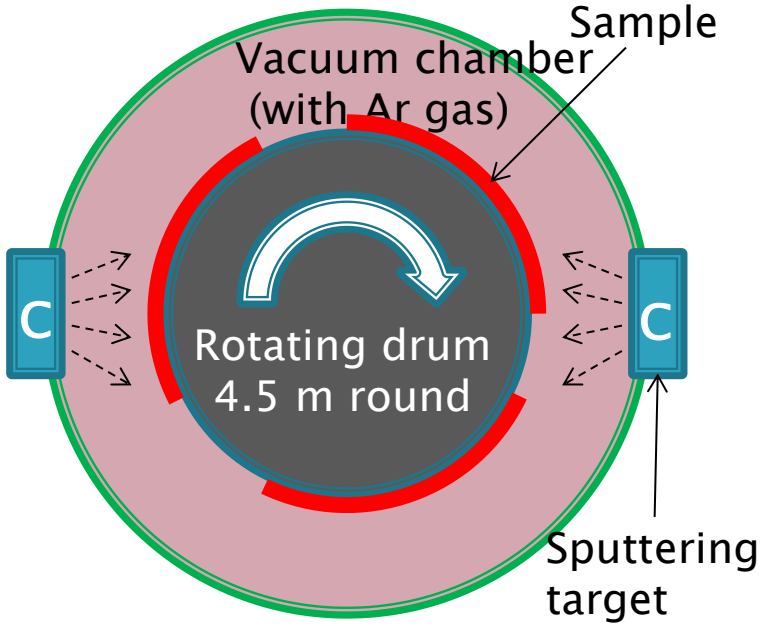






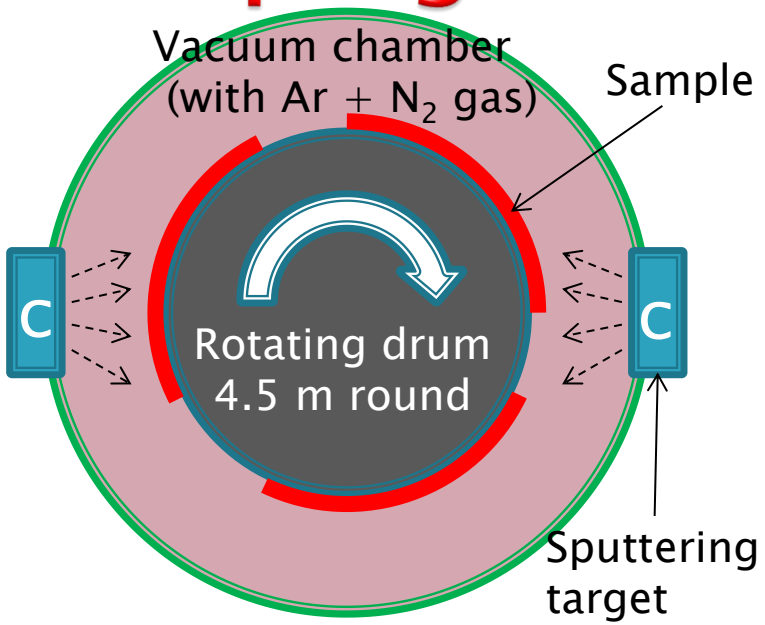
Pure carbon with two stations

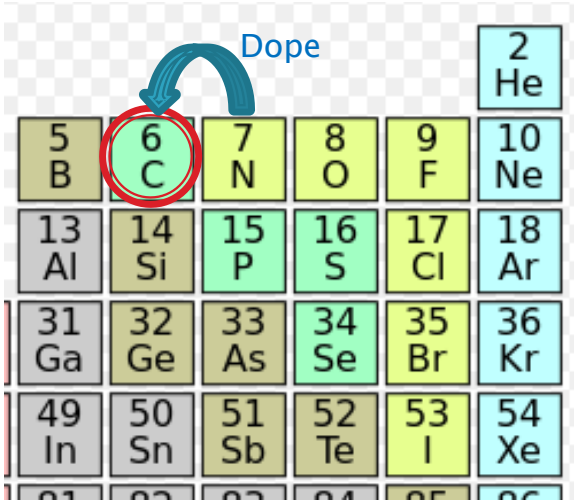
- For preparing double carbon target, we can reduce the sputtering time to half.
  - For 3600Å carbon foil, 6 hours → 3hours
  - It was great reduction, but we need more …
  - Can we reduce it to less than 1 hour ?



New idea: Nitrogen doping

- The structure of the sputtered carbon is amorphous diamond like carbon (a-DLC).
- It is thought that the charge carrier is very few in the DLC
- So, I got an idea of nitrogen doping as a supplier of carrier electrons.
  - This is same story as the n-type semiconductor production.
- The nitrogen is easy to introduce into the sputtering chamber with Argon gas.





N_2 doping – first trial (May, 2014)

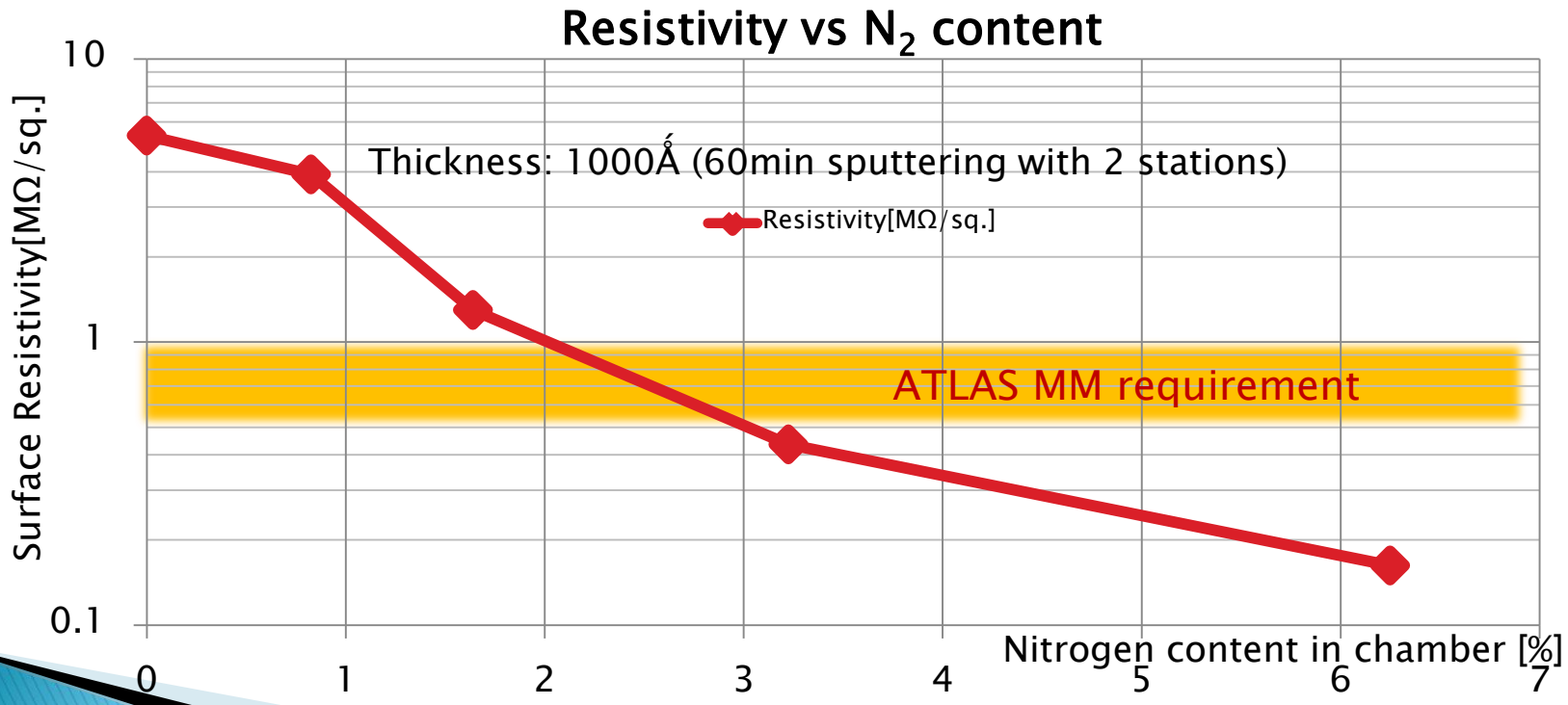
- For the first trial for N2 doping, following two samples were made and tested for 2hour sputtering.
  - 3.2 % N_2 gas in Argon gas
  - 50 % N_2 gas in Argon gas
- Results are very interesting

N_2 content	Thickness	Surface resistivity
0% (pure Argon)	2100 Å	2.1 MΩ/sq.
3.2%	2400 Å	0.055 MΩ/sq.
50%	3900 Å	46 MΩ/sq.

- Those trial were followed by systematic test for varying the N_2 (a few %) content and thickness

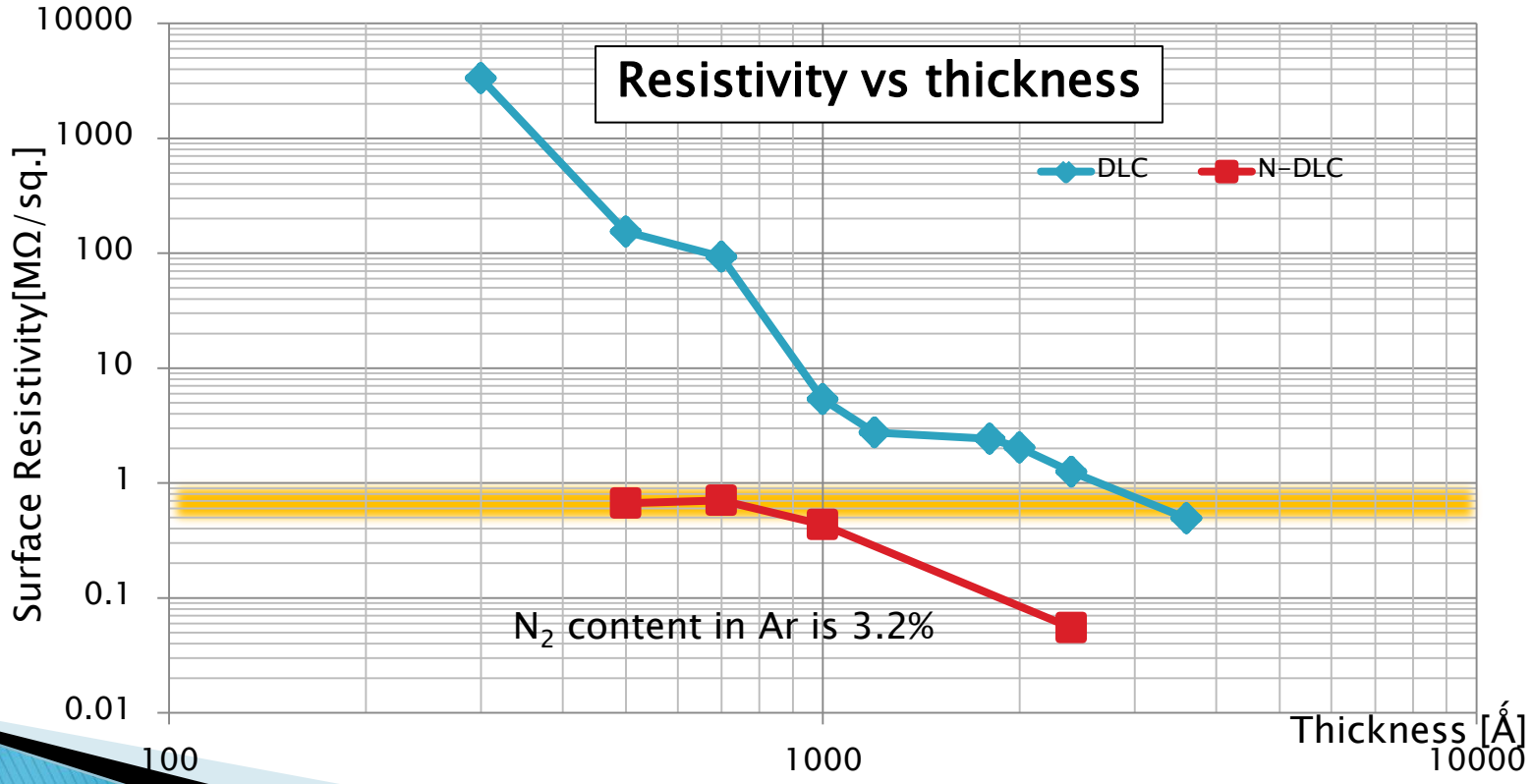
Resistivity vs N_2 content (June, 2014)

- The resistivity is strongly reduced by nitrogen doping.
- Surface resistivity of 1000Å foils:
  - Pure carbon → 5MΩ/sq.
  - 3.2% N_2 in Ar → 400kΩ/sq.



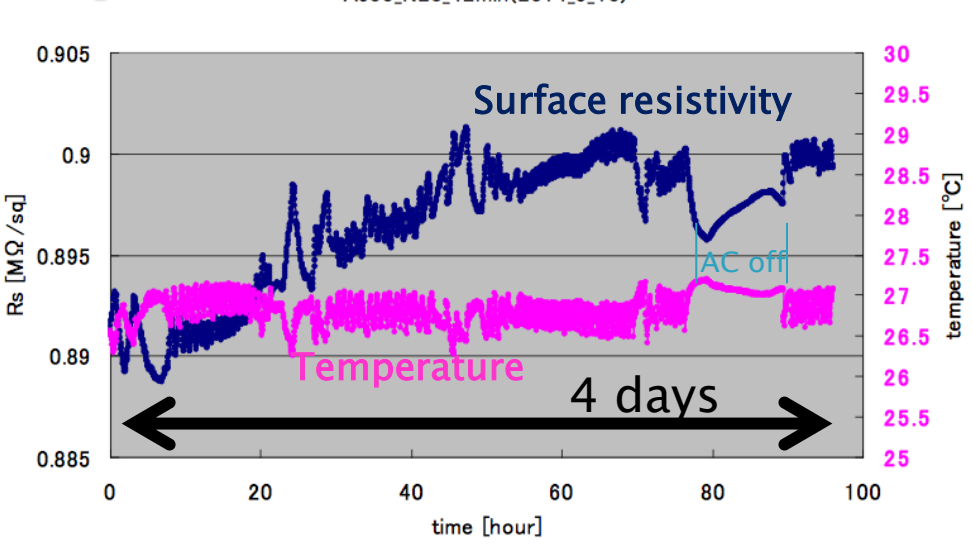
Resistivity vs thickness (June, 2014)

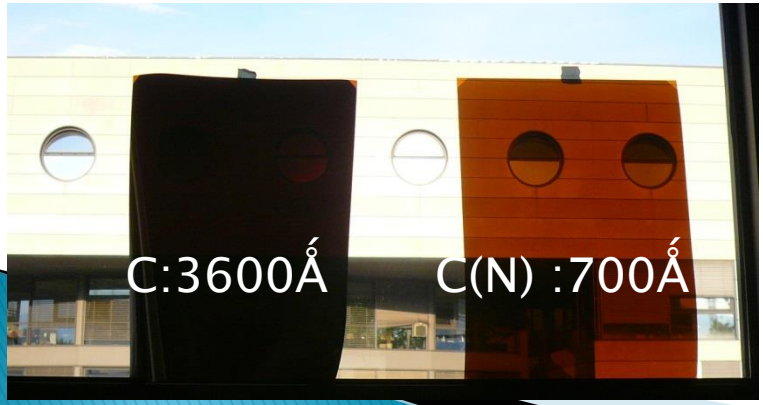
- For 3.2% N_2 content foils
  - 2400Å → 55kΩ/sq.
  - 700Å → 700kΩ/sq. (42min. sputter)

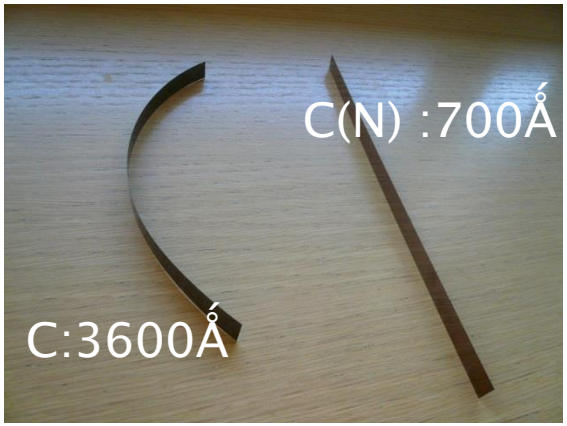


Properties of N-doped carbon foil

- 3.2% N-doped with 700Å thickness foil was tested.
- Stability of the resistivity
  - It will be ok
    - ~1% changing is observed in 4 days measurements, 4 days after sputtering).
    - It seems to be the balanced value.
  - We need more measurements
- Stress of the foil
  - Very small, comparing with the thick carbon foil.
- Mechanical and chemical tolerance check should be done
  - Same test as applying to thick(3600Å) foil







For ATLAS MM mass production

- The sputtering process is most time consuming.
  - We need [sputtering time] + 1.5 hours (load and eject the materials, vacuuming etc.) for one batch.
  - 6 foils can be sputtered in one batch.
  - For 2048 foils … 350 batch needed
- Estimation for production rate

Foil type	Time/batch	Batch/day (day work)	Batch/day (24h work)	Prod. period (day work)	Prod. period (24h work)
Thick carbon	4.5 hours	2	5	8.5 month	3.5 month
N-doped C	2.2 hours	4	10	4.3 month	2 month

Future prospects

- Test, test and test
  - Mechanical tolerance test
    - Peeling test
    - Bending test
  - Chemical tolerance test
    - Tolerance test for PCB related liquid
      - Tomorrow, at Rui's workshop
  - Stability test
    - Resistivity
    - Migration
- Fine pattern making with Liftoff process
- This technique will be used in Module-0 for ATLAS NSW MM
  - Also we will make small prototypes for aging test

Summary

- The new resistivity control technique for carbon sputtered foil is developed using Nitrogen doping
- Very wide range of the surface resistivity is available between 50kΩ/sq. and 4GΩ/sq., in our experience.
- The stability and tolerance test should be continued for N-doped carbon foil.
- N-doping technique is very promising for mass production process of ATLAS MM resistive foils.