Progress Report on IAEA Dust CRP: Statistics on dusts in KSTAR, Dust transport and removal experiments in TReD

Suk-Ho Hong

Establish strategy for dust database

- To be sure that dusts are created by plasma-surface interaction, and not during the maintenance, silicon wafer samples should be installed after the maintenance, just before the machine closing.
- To establish time-resolved database for temporal evolution of dust creation, shape, number density, silicon wafers should be installed everyday, in the morning.
- Dust creation during/after disruptions can be identified by scattering measurements (Thomson system).
- Dust impact on the first wall can be obtained by analyzing impact craters on coupon holders.
- Dust detection and removal in TReD.

Measurements and Analysis

- Only use standard definitions and methods.
- SEM, EDX, Thomson signal, and CCD images are analyzed.
- Statistics of database from ImageJ is built.
II. Validation of Methods and Procedures

- **Shape description depends strongly on magnification (minimum pixel size), brightness & contrast (edge structure).**
- Observation area by SEM has to be large enough to get reliable number density of dusts, but not so large to get correct shape description.
- Pixel threshold should be defined to show clear edge of dusts with minimum number of “1 pixel”.
- Size threshold should be defined to detect dusts correctly, not “noise” due to contrast (e.g., larger than 4 pixels).

### Standard Parameters

- **x500**: 588 nm/pixel
- **x1000**: 293 nm/pixel
- **x5000**: 75 nm/pixel
Ⅱ. Validation of Methods and Procedures

Validation of IMageJ

- To be sure that ImageJ gives correct statistics on shape, size of “known particles”, at least correct size distribution.
- To establish error-bars depending on operating procedures and image threshold.
- To find out optimum processing parameters such as brightness & contrast, magnification. This is important for the standardization of the database.

Experimental Setup

- Coins with different radius.
- “Different reflection” and “effect of flash” would be similar with to “difference in contrast” due to surface structures of dusts.
II. Validation of Methods and Procedures

**IMageJ testing procedure**

1. **original**
2. **Grayscale**
3. **Measurement**
4. **Applying threshold**
II. Validation of Methods and Procedures

ImageJ testing procedure

- Original image with good contrast between objects and background shows good results after applying threshold.
- All objects are correctly detected with areal threshold of 1 cm².
- Some objects show the effect of threshold on the shape and size.
II. Validation of Methods and Procedures

- **IMageJ testing procedure**

<table>
<thead>
<tr>
<th>Size (cm^2)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>10</td>
</tr>
<tr>
<td>1-2</td>
<td>50</td>
</tr>
<tr>
<td>2-3</td>
<td>100</td>
</tr>
</tbody>
</table>

- **Exact histogram**

- **Measured histogram**

- Similar results.
- Due to imperfection of edge structure of the objects, there is some errors in measurements.
Ⅱ. Validation of Methods and Procedures

IMageJ testing procedure

- Original image with brighter background shows similar results, but brighter background would be problematic.
- Darker background is preferred (or adjust brightness/contrast).
Ⅱ. Validation of Methods and Procedures

- IMageJ testing procedure

- Similar results.
- Due to imperfection of edge structure of the objects, there is some errors in measurements (shifted towards smaller size).
Dust sampling in KSTAR

- Daily samples on silicon wafer by deposition probe system.
- Campaign integrated samples on silicon wafer at vertical K port.
- Vacuumed dust samples from divertor region after the campaign.
- Samples detached by carbon tapes.
Ⅱ. Validation of Methods and Procedures

Dust database from ImageJ

- ImageJ gives inputs for IAEA dust database.
- Size, number density, and shape descriptor (circularity, roundness, elongation) were further analyzed.
- Temporal evolution of dust size, shape, number density are obtained.
- Chemical composition is analyzed by EDX.
- Standard magnification: x1000 (0.293 um/pixel) or x5000 (0.075 um/pixel).
- Threshold for detection: 5 pixels - infinity
IV. Some statistics on dusts in KSTAR

Daily dust collection by deposition probe at midplane

- First day: Large size broken graphite pieces.
- 5 days later: Smaller, but elongated graphite pieces + nanoparticles + droplets.
- 7 days later: due to damage of the passive stabilizer (a tile fallen), larger graphite pieces are observed. Note that the elongation of dusts decreases and shape of many dusts are rounded (increase of circularity).
- Afterwards, it is clearly seen that dust size decreases.
- most of dusts collected by DPS are carbon-based.
- More data will be analyzed.

2011.06.08
First day

2011.06.13

2011.06.15
Tile broken

2011.06.22
IV. Some statistics on dusts in KSTAR

**Daily dust collection**

- Mean occupied area decreases while the number density increases.
- Mean circularity and elongation increase as a function of time (definition of elongation in ImageJ!) → more and more rounded.
- Mean roundness is about ~0.5.
IV. Some statistics on dusts in KSTAR

2011.06.15 9:44 camera
- Tile OK.

2011.06.15 17:42 last plasma of the day
- Camera stopped before the plasma termination.
- Heavy disruption shot.

2011.06.15 17:45 camera
- A tile was fallen at upper passive plate.
IV. Some statistics on dusts in KSTAR

2011. 08. 12 15:33
# 6196 shot: a disruption shot. A tile was pulled out by EM force during the disruption.

2011. 08. 12 16:24
# 6200 shot

2011. 08. 12 16:57
#6203 shot: tile fallen down.
# 6204 shot: tile is located at divertor.
IV. Some statistics on dusts in KSTAR

**Daily dust collection**

- Small size particles have more rounded shape, while larger particles have low circularity (not round+complex edge structures).
- Mean circularity and elongation decrease as a function of radius.
- Particle number density as a function of radius decreases exponentially.

![Graphs showing mean value, mean effective radius (μm), mean circularity, mean roundness, and mean elongation as functions of mean effective radius (μm).](image)
- Large portion of dusts are rounded, so “effective radius” of dusts is calculated assuming surface area and volume have simple relation.
- Most of dusts have effective radius in the range between 0.075-3 µm, peak @ 0.115 µm. Total mass of dusts (extrapolated) during the analyzed period is ~122 mg (average ~7mg/day).
IV. Some statistics on dusts in KSTAR

Campaign integrated dust collection at vertical port

- The silicon wafer is installed just before the plasma operation period.
- Large size broken graphite pieces, stainless steel, copper, etc.
- Various shapes (circularity & elongation peaks at 0.7), flake-like dusts are observed.
- Areal distribution from 0.43-1701 um² (peak at ~2 um²).
- More data will be analyzed.
IV. Some statistics on dusts in KSTAR

Input files for IAEA dust database

- Standard magnification of x1000, x5000
- Standard brightness and contrast (cont ~30, brightness ~50).
- 2 TIF pictures (SEM original+outlined picture from ImageJ).
- ImageJ output file with ImageJ format+EDX included.
- Machine & campaign information.
- Numbering of dusts is underway because of identification of particles by eyes, and match SEM and EDX.
- Other input files will be ready.

Difficulties

- Painful measurement and analysis time (SEM, EDX, etc...).
- Matching SEM and ImageJ index.
- Inserting EDX data into ImageJ output.
Dust creation zones and events by CCD image analysis

- Conversion to the grayscale images
- Filters for noises
- Subtraction between the target frame and the background frame
- Conversion to the 1bit black and white (BW) images
- Counting dust particles, integrating frames
  (The frequency of the events / The creation zone of the dust particles)
Dust creation zones and events by CCD image analysis

Development of automatic data extraction technique from visible CCD images for in-vessel dust study in Tore Supra

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Temporal evolution and spatial distribution of dust creation events in Tore Supra and in ASDEX Upgrade studied by CCD image analysis

Suk-Ho Hong\(^1\), Christian Grisolia\(^2\), Volker Rohde\(^3\), Pascale Monier-Garbet\(^2\), Tore Supra Team\(^2\) and ASDEX Upgrade Team\(^3\)
IV. Some statistics on dusts in KSTAR

- In 2010, limiter+divertor operation.
- DCEs with limiter operation are random (also observed in TS).
- DCEs with divertor operation are localized at divertor (also in AUG).
- DCES at upper passive stabilizer is due to the droop of the structure caused by frequent VDEs.
IV. Some statistics on dusts in KSTAR

Dust creation zones

Droop of passive stabilizer
IV. Some statistics on dusts in KSTAR

Dust creation zones

Droop of passive stabilizer
IV. Some statistics on dusts in KSTAR

Dust creation zones

DCEs in Tore Supra CIMES campaign

DCEs in AUG 2007 campaign

S. H. Hong et al, Nucl. Fusion 50 (2010) 035002
IV. Some statistics on dusts in KSTAR

Dust creation events during the campaign

Plasma operation time: ~2514s (2010 Campaign)

#3398~3425  
D shaping  
#4188~4209

Plasma operation time: ~6391s (2011 Campaign)

#5074~5099  
#5144~5163  
#5272~5297  
#6172~6204

Number of events per seconds

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<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
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<tbody>
<tr>
<td>NEPS</td>
<td>1.8878</td>
<td>2.741</td>
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<tr>
<td>Duration (s)</td>
<td>2543.8s</td>
<td>4316.3s</td>
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</tbody>
</table>

Range of NEPS in AUG: **0.5-4**
Dust velocity distribution

KSTARTV2011 program [2]

- Identify the plasma position.
- Measure the well-defined straight line-like trajectories of dust along the toroidal direction.
- Measure θ both ends of dust trajectory.
- Trajectories at inboard side.
- Dusts can not get through into the core plasma.

- Measure 1237 trajectories.
- Velocity range 7 ~ 385 m/s.
- Peak at 30 m/s.
- Exposure time : 3 ms.

- Measure 1821 trajectories.
- Velocity range 9~412 m/s.
- Peak at 50 m/s.
- Exposure time : 1.5~4.8 ms.
V. CDG & TReD Experiments

Dust detection by CDG

- We have manufactured circuit suggested by Dr. G. Counsell et al.
- We have tested the CDG with suggested settings and parameters.
- However, we have best response from CDG with:
  - second amplifier gain=1.
  - square wave of 100 kHz (higher impedance of chipset).
V. CDG & TReD Experiments

Dust detection by CDG

Figure 4.6 Sensor calibration using copper wire weights applied close to the centre of the diaphragm.

G. Counsell et al., EFDA task TW1-TVP/dust

3.2 Load applied at centre

Application of a load \( W \) to a very small area at the centre of the diaphragm is illustrated schematically in Figure 3.2. In this case, the deflection \( y \) at any radial distance \( r \) from the centre of a diaphragm of radius \( a \), fixed at its outer edges, is given by

\[
y = \frac{W}{16\pi D} \left[ a^2 - r^2 \left( 1 + 2\ln \frac{a}{r} \right) \right]
\]

where \( D \) is the plate constant as described previously.
V. CDG & TReD Experiments

Dust detection by CDG

- Loading/unloading test with deflection at center.
- Minimum detectable mass = 1g (low detector sensitivity due to low amplification in the range of 0-3 g).
- Linear response between 3-5 g (sensitive enough to detect ~mg).
- From 5 g, signal is no more valid.
Dust detection by CDG

Load weights randomly

- To get dust weight only at center, “dishes” are tested.
- Dome-type shows more reliable measurements even with random deposition of weight.
- Care must be taken for the contact between dish and diaphragm.
- More test will be done and CDG will be installed at TReD and KSTAR.
V. CDG & TReD Experiments

Dust removal by TReD

Electrodes (Tri-polar grids)
9 mm x 450 mm

Dust collector spot

1.2 m
V. CDG & TReD Experiments

Dust removal by TReD

- Measure CDG response to plasma-transported dusts with known mass.
- Measure removal efficiency of dusts.

Experimental Setup

- Powder: Al₂O₃, 5um
- Base pressure: 2.5 * 10⁻³ Torr, Only rotary Pump
- Operation pressure: 2.5 * 10⁻¹ Torr, MFC 200 SCCM He
- RF Power 34W: rf 7W

Dispenser

- Used boozier: Piezo Boozer, 1000Hz
- Size
  - Outer diameter Φ29, inner diameter Φ6.5
  - Φ27 diaphragm
- 3 Dispensers, each 100-300mg dusts loaded.
- Dispenser operating V: 16~26

- Electrode: no bias potential
- Al paper is placed on the electrodes,
  - 150mm * 150mm
IV. Some statistics on dusts in KSTAR

Dust removal by TReD

- Measure CDG response to plasma-transported dusts with known mass.
- Measure removal efficiency of dusts.

1. Collector
2. Al paper 1.
3. Al paper 2.
5. Dispenser 1.
6. Dispenser 2.
7. Dispenser 3.
V. CDG & TReD Experiments

Dust removal by TReD

- Measure CDG response to plasma-transported dusts with known mass.
- Measure removal efficiency of dusts.
## V. CDG & TReD Experiments

### Dust removal by TReD

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<th>⑤</th>
<th>⑥</th>
<th>⑦</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>14.10g</td>
<td>8.80g</td>
<td>8.24g</td>
<td>8.45g</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>After</td>
<td>14.19g</td>
<td>8.80g</td>
<td>8.25g</td>
<td>9.04g</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>remain</td>
<td>0.09g</td>
<td>0g</td>
<td>0.01g</td>
<td>0.59g</td>
<td>0.03</td>
<td></td>
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</tr>
</tbody>
</table>

- About 10% of dusts (e.g., ~90 mg from 900 mg) reach the collector.
- Dust removal efficiency is about 5-10 mg per hour (unoptimized).
- Calibrated amount of dusts will be reached the CDG by plasma-transport.
- Detection efficiency of CDG will be determined.
VI. Summary

- Dusts database for IAEA CRP is built in KSTAR.
- Using the information obtained from the database, some statistics on dusts in KSTAR are obtained.
- CDG test and optimization of measurement are ongoing, together with TReD experiments.
- Dust removal efficiency in TReD is about 5-10 mg per hour with “unoptimized condition” (total amount of dusts (extrapolated) collected during the analyzed period in KSTAR 2011 campaign by DPS is ~122 mg, average ~7 mg/day).