Triboplasma - its generation and application for surface modification

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3 Summary
1.1 What is a plasma?

Characteristics of low temperature plasma

- Non-equilibrium \((T_{\text{electron}} \gg T_{\text{ion}}, T_{\text{molecule}})\)
- Radicals, ions, electrons
- UV emission
- Surface modification, Polymerization, film synthesis
- Environmental compatibility
- High treatment effect
- High reproducibility
- Bulk property unchanged
- Easily generated at low pressures, but also possible at atmospheric pressure
1.2 Atmospheric pressure plasmas

need power supplies
2 Triboplasma

2.1 Processes with tribological activation

Triboemission

Emission of electrons, ions, radicals, photons, phonons etc. caused by tribological activation

Tribo-luminescence

Optical emission caused by the breaking of asymmetrical bonds in a material with tribological activation

Triboplasma

Gas discharge with tribological activation

Surface modification
2.2 Magna-plasma model

Impact stress of flying grain
quasi-adiabatic energy accumulation
formation of energy bubble
at the deformation zone
high excitation states
strong lattice loosenings
structural disruptions
detachment of lattice components,
photons, ions, electrons

Generation of triboplasma

Temperature by rubbing peaks
between 600 - 1000 K in the course of
period smaller than $10^{-4}$ s, leading the
hot-spot theory.

based on Thiessen “Grundlagen der Tribochemie” 1967
& Heinricke “Tribochemistry” 1984
2.2 Magma-plasma model

Ceramization with Rocatec (3M) – dental application

$\text{SiO}_2$ coated alumina particles are blasted onto a surface.

A triboplasma is generated at the contact.

$\text{SiO}_2$ coatings are partially delaminated from the particles and attached onto the blasted surface.

The alumina particles are removed.

Detection of a triboplasma is not reported.

2.3 Tribo-electrification model


strong impact unnecessary!
2.4 Generation of triboplasma

Observation of optical emission around the sliding contact

Intense UV emission NOT at the sliding contact

Materials with higher resistivity show higher charge-emission intensity

(Nakayama, Tribology Lett. 6 (1999) 37-40)

Supporting tribo-electrification model
2.5 Tribo-electrification

The production of electro-static by rubbing together of dissimilar material surfaces.

The detailed physical mechanism in tribo-electrification is a long unsolved problem

Tribo-electric series
- a classification scheme for the ordering of the tendency for charge acquisition in rubbing

Surface morphology
2.5 Tribo-electrification

Tribo-electric series

Air (*?)  positive  Borosilicate glass (ground surface)
Human hands  Amber
Asbestos  Sealing wax
Rabbit fur  Natural rubber
Silicone elastomer with silica filler  Nickel, Copper
Borosilicate glass (fire polished)  Brass, Silver
Glass  Gold, Platinum
Mica  Sulphur
Human hair  Acetate, Rayon
Nylon  Polyester
Wool  Polystyrene (Styrofoam)
Fur  Orlon
Lead  Saran
Silk  Polyurethane
Aluminium  Polyethylene (PE)
Polyethylene (PE)  Polypropylene (PP)
Polypropylene (PP)  polyvinylchloride (PVC)
Paper  Silicon
Cotton  PTFE (Teflon)
Steel, iron  negative
Wood

Adams "Nature’s electricity 1987, Freeman_ Mater.Sci.Technol._1999. Note that the order of the above list is different in different books"
2.5 Tribo-electrification

Tribo-electric series (polymers)

Coehn’s law: the order of materials corresponds with that of dielectric constants

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon</td>
<td>4.0 – 4.5</td>
</tr>
<tr>
<td>PMMA</td>
<td>3.0 – 3.5</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>2.4 – 2.65</td>
</tr>
<tr>
<td>polyethylene (PE)</td>
<td>2.25 – 2.35</td>
</tr>
<tr>
<td>PTFE (Teflon)</td>
<td>2.0</td>
</tr>
</tbody>
</table>

“contact and separation” is important for charging. Some surfaces, such as adhesive tape or plastic sheets, can attain intimate contact over a large area, and do exhibit strong charging when they are simply touched to another surface and pulled away.

http://amasci.com/emotor/tribo.html
The ordering of the tribo-electric series can be different when surfaces are rubbed or simply touched, or surfaces of differing roughness are rubbed together.

- Asymmetric rubbing
- Asymmetric heating
- Greater charge supply from a contaminant at the larger area
- Concentration of mobile carriers increases
- Charge transfer from hotter to cooler (smaller area to larger area)
- Charge transfer from larger area to smaller area
2.5 Tribo-electrification

Controllability of tribo-electrification

- physical and chemical nature of the contacting surfaces (bulk properties, surface morphology, surface layers of water, oxides, hydrocarbons, dusts etc.)
- pressure and duration of contact
- heating, transfer of bulk materials
- ambient medium
2.6 Surface modification by triboplasma

Good agreement of optical emission spectra between a triboplasma and other general discharge plasmas

A triboplasma can be useful for surface modification such as adhesion improvement of certain surfaces

Potential advantages
• simple system
• simultaneous mechanical rubbing to enhance the treatment effect.

Fluoropolymer lubricant is decomposed
Polymeric coatings can be synthesized by a triboplasma
(K. Nakayama, Tribology Int. 29(5) (1996) 385-393)
2.7 Experimental setup

From the side

sphere

balance

bearing

sample (rotating disk)

load cell

wear track

From the top
3 Summary

- Processes with tribological activation
- triboplasma by tribo-electrification
- mechanisms of tribo-electrification
- surface modification effects
- experimental setup