EUROPEAN APPROACH TO MATERIAL CHARACTERISATION FOR PLASMA INTERACTION ANALYSIS

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Abstract

The European Space Agency (ESA) has initiated an activity on material characterisation for plasma interaction analysis.

This work is part of a mini-project in the frame of the ESA Technology Research Program, which is also covering two other main aspects of the research and industry community needs, i.e.

(1) Spacecraft plasma interaction analysis and simulation software toolkit and
(2) Guidelines for spacecraft charging and plasma interactions.

The activities in the three parts will be harmonised in the framework of SPINE (Spacecraft Plasma Interaction Network in Europe).

The main objectives of the activities described in this paper are:

(1) Definition of required material characteristics needed for the different simulation software, the comparison of different characterisation techniques and the available test houses in Europe.
(2) Design of a database for relevant properties on materials used in spacecraft manufacturing; largely concentrated on external surfaces.
(3) Collection and integration of existing, and verifiable, material property data into an easy accessible database, compatible with the software under development.
(4) Measurement of properties on a set of newly proposed materials.

Special attention will also be drawn to the influence of other environmental parameters onto these properties, natural ones, such as solar radiation, as well as induced ones e.g. contamination, material ageing, temperature.

The paper presents the approach taken to achieve the objectives above, and gives the most recent developments in the different parts of the activity.

Introduction

The need for modelling of spacecraft plasma interactions in Europe becomes more and more obvious. Deleterious charging interactions are well known to occur in nearly all orbits (GEO, MEO, Transfer, and even LEO) and have in the last decades and also in the recent past led to so called "anomalies", leading in extreme cases to a definitive failure of the system. For instance, charging and (subsequent) discharging has caused recently severe and definitive damage to solar arrays. So, the charging and discharging effects might jeopardize the nominal operation of a satellite. The risk for attaining critical differential charging levels (range of kVolts) is clearly dependent on the use of insulators as external coatings (polymers, paints, glasses), unable to dissipate the incoming charged particles from the environment, and able to accumulate and store charge, up to critical discharging levels.

Furthermore external coatings of scientific satellites are most often required to be completely conductive. The concerns are the instruments measuring the low energy plasma: the measurements are affected by the (positive) satellite potential induced by photoemission. Measuring photoemission properties together with the energy distribution of the photo-emitted electrons is a real challenge to be tackled in this project.

The need for a capability of modelling spacecraft plasma interactions is obvious for a large community of users such as those in Europe including space research agencies (ESA, CNES), space industries, and scientific experimenters.

As a result of this need, SPINE was created in 2000. SPINE stands for Spacecraft Plasma Interactions Network in Europe. The objective of this network is to share resources and to co-ordinate efforts in all domains related to the interaction of spacecraft with the space plasma, including:

- Development of numerical analysis methods and algorithms, software architecture and data interface (code implementation, validation techniques, testing and post-processing, common Library of generic routines for s/c-plasma-interaction simulations).

- Development of a database on material properties, environmental data and space flight observations.

- Development of a Database of results and publications.

- Access to Environmental data

- Preparing in orbit investigations

- Establishment of standard procedures and method for hardware design, including qualification and testing

- Training of young scientists and engineers.

- Establishment of External collaborations

  In this general frame, ESA planned a mini project in the field of Spacecraft plasma interactions covering different aspects of the research and industry community needs.

  Next to the database for characterisation of material properties, the main topic of this paper, the two other main aspects covered are:

- A toolkit for spacecraft plasma interaction analysis and simulation software

- Guidelines for spacecraft charging and plasma interactions.

(1) A toolkit for spacecraft plasma interaction analysis and simulation software

The development of the analysis and simulation software toolkit, called SPIS (Spacecraft-Plasma Interaction System) has been started beginning of 2003.

It includes a general infrastructure, allowing a convenient embedding of an increasing number of modules, or routines. Within the contract, the contractor is responsible for the design and implementation of the framework as well as the implementation and integration of some of the numerical routines.

The SPINE community has been able to provide guidelines or requirements so that this software will answer its needs; It is also requested to develop some of the routines and to test the software on a number of pre-defined test cases.

(2) Guidelines for spacecraft charging and plasma interactions.

The guidelines for the spacecraft projects will address the need of the space research and space industry community for the assessment of problems related to spacecraft plasma interactions.

It will also promote the use and the sharing of European resources, especially regarding knowledge and expertise for spacecraft design and operations and test facilities.

The guidelines shall consist of a paper version, including text and graphs of the guidelines, and a public interactive version that shall include simple formula computational capabilities and a list of assets and contact points for support and access to facilities and expertise.

Identification of Needs

The identification of needs for the material characterisation programme is believed to be of outmost importance because it appeals to basic physics, it will drive several tasks in the frame of this activity, and it requires contacts with the users community.

The view of the needs might evolve in time, e.g. after attending to the SPINE meetings or as a result of exchange with the community users. Recommendations for updating the existing facilities could be formulated during this project.

The physics incorporated into NASCAP or other charging codes shall be reviewed and the need of new properties or of different modelling of a given process will be searched from basic physics and needs expressed by the users community (Spine). The importance of material properties for local charging (at material level) and overall charging of a satellite (absolute charging) will be addressed.

Although through performance of numerous NASCAP simulations with variable parameters, an assessment of the sensitivity of charging to given material properties could be made, this information is felt to be too coarse and is already known through previous NASCAP sensitivity studies; The basic outcome is the importance of secondary emission(s) and conductivity(ies). An alternative approach allowing an extended testing of properties sensitivity is proposed. It will use simple 0D codes to compute current balances in specific situations, as e.g. charging effect in GEO in presence of potential barrier, or enhancement of currents through secondary emission (effects of snapover, multipactor, hopping along a surface…), or photo-emission-driven charging situations. The required accuracy for each property will thus be determined in regard to their relative impact on the charging. Codes, similar to EQUIPOT in SPENVIS, but using other customised laws will be written for this study. These 0D codes may require information from 3D codes (e.g. potential barrier height in GEO as a function of differential charging), which will be obtained from analytical computations or numerical runs of in-house codes (e.g. ONERA code SILECS).

Material properties are not stable during the orbital life of a satellite and consequently, the properties should be measured according to agreed methods with considerations of environmental and ageing effects. Secondary emission and photo-emission are surface properties which are affected by contamination effects (all orbits are concerned) or by structural effects from atomic oxygen (LEO). Surface conductivity is also highly dependent on contamination and adsorbed gases. Conductivity is dependant on the applied field, on the temperature, on the (instantaneous) dose rate (Grays/s) and on the history (accumulated dose in Grays). Photo-conduction (a kind of radiation induced conductivity) has similar effects on coloured materials (Kapton is an example of a highly sensitive photo-conductive material).

Applicable Test Methods and Available Test-Houses

Recognising the need for material characterisation, e.g. when charging problems and related anomalies were recognised as a threat for the nominal operation of satellites, the European users have already developed in house capacities. An inventory through Europe of available facilities for the measurement of different properties will be made. The applicable test methods for the properties determination will be reviewed. Preferred methods and procedures will be stated.

In the field of material charging in the space environment, ONERA-DESP has many facilities, and has performed many studies and material measurements. Facilities and measurement methods in the field of secondary emission have also been developed at ICMM/CSIC. Each facility implies a cost (development, maintenance) making a common development at European level very cost-effective. ONERA-DESP and ICMM/CSIC will join their expertise in a collaborative program set up in the frame of this activity. This is a framework which in the future will hopefully not be limited to these test houses, since after the test houses facilities will be reviewed, a proposal for developing or adapting new facilities cannot be excluded.

Pushed by space industries to meet their needs, and supported by space agency R&D efforts, ONERA-DESP and ICMM/CSIC have developed and maintained such facilities: CEDRE : CEDRE is equipped with low energy electrons (5-35 keV) for dark conductivity measurements. It features a temperature controlled holder, and much of DESP work on Kapton, Teflon, Cover glasses, paints was performed (with temperature effects) on this facility.

SIRENE: SIRENE is a more sophisticated DESP facility. It combines a high energy accelerator (400 keV Van De Graaff) and a low energy electron gun (5-20 keV). It has the unique feature to reproduce the geo-stationary electron spectrum (a stormy day, in the range of 10-400 keV). It allows a much more realistic assessment of voltage build-up in geo-stationary orbit since it involves both the charging (low energy) surface electrons, and the penetrating electrons able to enhance the material conductivity. The spectral range (10-400 keV) allows the study of materials up to 300 µm thickness, well fitting with most common external materials.

JONAS: Jonas is the DESP big plasma chamber to simulate the ionospheric plasma environment: high density and low energy plasma. Jonas can receive very big (meter size) samples. It combines a low energy electron gun with the ionospheric plasma and is fitted for experimental studies of wake charging (likely to occur in the polar LEO due to auroral precipitation).

LH 10 & VG ESCALAB (secondary emission facilities): ICMM/CSIC has developed facilities and expertise in surface physics. The equipment features Auger spectroscopy, secondary emission yield measurement, residual gas analysis and electron stimulated desorption measurements.

OTHER EUROPEAN FACILITIES (not in this consortium): All test houses in ESA member states should be listed. In Germany, the university of Giessen has been active as well as PTS in Freiburg. In the United Kingdom, QinetiQ is using radioactive strontium sources to investigate internal charging. Some Universities in Europe might as well have high-energy accelerators or low energy electron or ion guns, (basic equipment used in a variety of fields of physics).

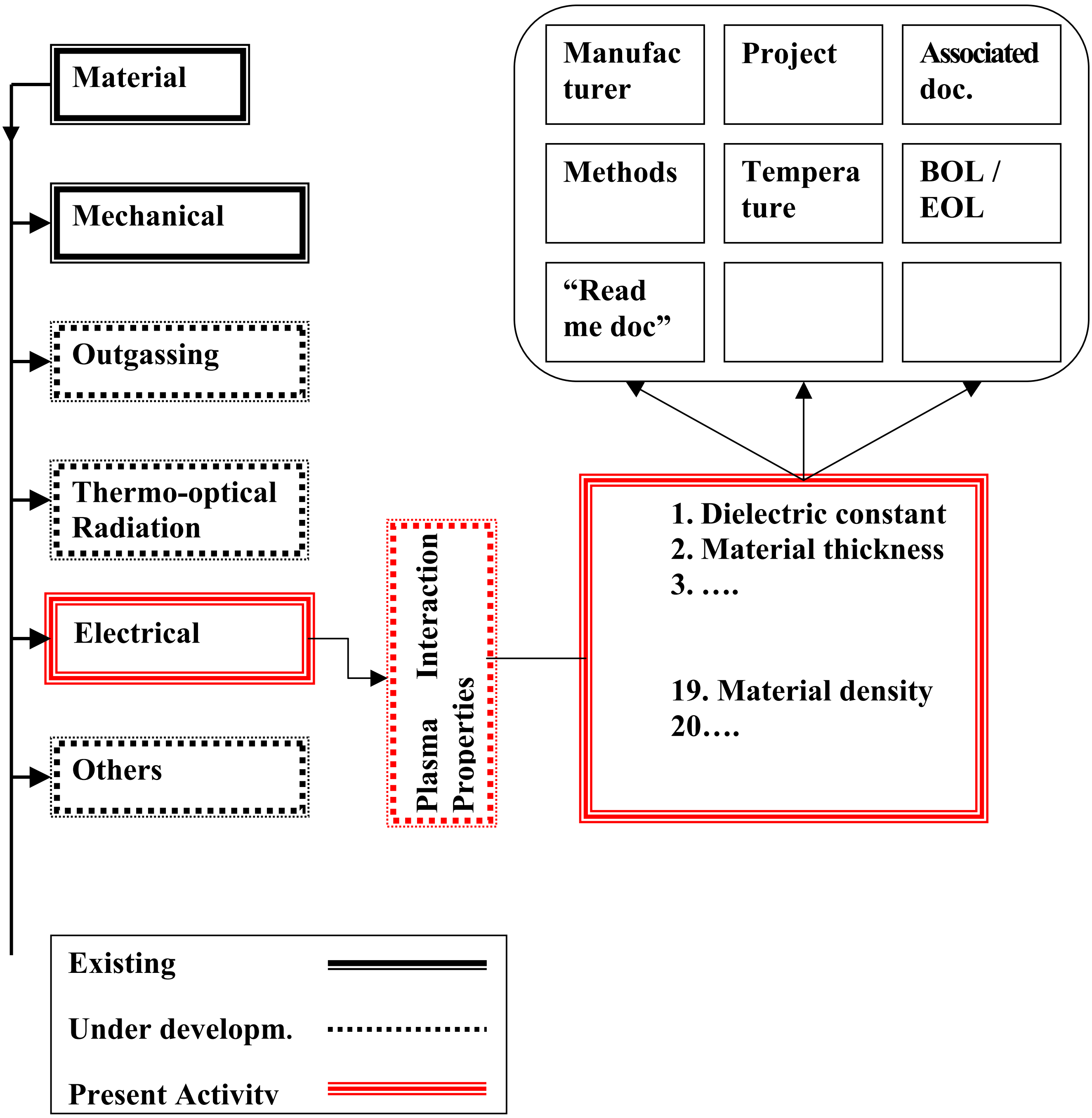
Design of Database

It was considered important to build a database compatible with other already existing databases. This would save considerable effort (reusing database basic structures) and allowing importing and exporting data from other sources. In the frame of a partnership between ONERA and CNES, ONERA will use an already existing database (ARCAM = Aide à la Recherche des CAractéristiques des Matériaux), developed by CNES using Access as a tool. The database documents many materials related to European projects and a dedicated module is under study to include special material properties for space applications (outgassing, thermo-optical and radiation effects).

It is proposed to use the same database and add to it an "electric properties" module, to enable within this structure to exchange files already existing between ONERA, CNES and ESA. Specific interrogation requests will be defined.

The basic request for data will be by specifying the material. All the properties will then available so they can be either read or transferred as a file.

For each property, links will allow retrieving information about the data origin (article or report reference), and a summary of relevant attached conditions (temperature, value at beginning of life or after ageing test, history, contamination,..).



All data belonging to the public domain (published articles, data obtained in the frame of an ESA contract) will have a free access status for the Spine community. The SPINE community is diverse, including agencies, research institutes, universities and research laboratories.

Information on materials might be created on a private basis, the initiative coming from a company that would like to keep information confidential and proprietary. Such proprietary data will have a "protected status", i.e. limited access.

ESA's responsibility is to regulate the access to the database. Access will be given on condition to companies and organisations within the ESA member states.

The database will contain basic information about how the data is obtained (methods). The methods will be described in an informative didactic "read me" document.

The database will include editing possibilities to list all the materials inside the base, and the range of extreme values for each property.

The database includes also possibilities of editing the list of non-measured materials or non available properties.

Collection and integration of existing material properties in the database

The database will provide existing data to users and it will be first filled with already available data. When further data are produced, the database shall be updated.

In order to guarantee the validity of the data incorporated in the base, the different measuring methods shall be reviewed and recommendation for a preferred one (if possible) will be issued. The data shall give information about the method which was used to produce it. Full or restricted accessibility to the database shall be set up in close agreement with ESA.

The need of updating the database will depend on the production of new data on already existing materials or on new materials. A team will formally and periodically keep in contact to assess the status and importance of new data and the need of updating. Therefore, a group of identified personnel involved in material properties will be formed to evaluate the information. The group will communicate through a "moderator", collecting and dispatching available (non proprietary) information.

The database will document not only the existing and available data, but also give additional relevant information (how it was measured, article reference, etc).

Measurement of Properties on a Set of Proposed Materials

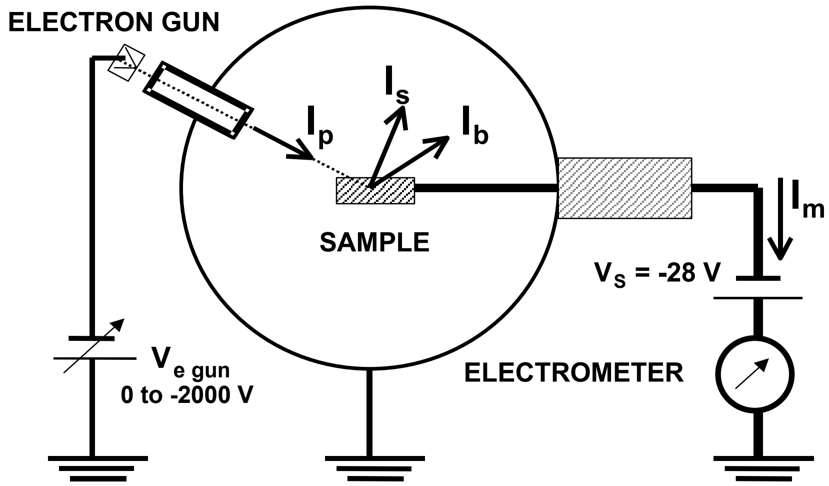
New materials (on use today or scheduled for use in the future) or new properties should be measured. An experimental program will be set up for a number of materials with considerations of environmental and ageing effects.

Users, i.e. through space industries, agencies and the Spine community, will be invited to express their non-covered needs. This should reveal required properties are not available.

This will help driving efforts towards new materials, new properties and eventually designing new (or adapted) facilities and measurement methods.

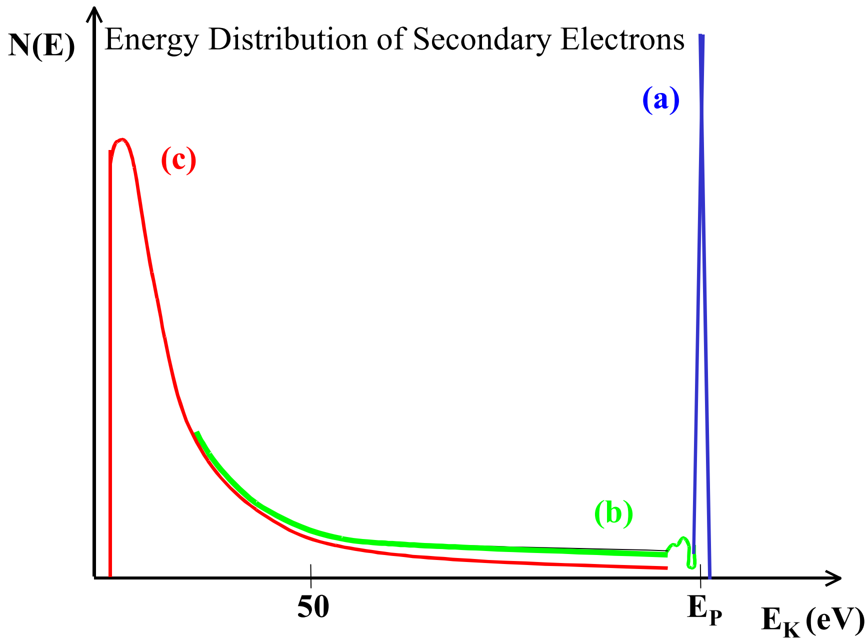
As already indicated, one of the properties playing a major role in the charging of spacecraft is the secondary electron emission.

The experimental set-up for the measurement of secondary electron emission yield is given below.



Experimental set-up for Secondary Electron Emission (SEE) measurements

The sample (to be measured) is irradiated with a calibrated electron gun. The figure below indicates the different categories of electrons re-emitted: The true secondary electrons (I_s), backscattered primary electrons (part of I_b) and elasctically reflected electrons do not have the same energies.



Three categories of electrons reemitted by the surface
(a = reflected primaries; b = backscattered ; c = true secondary)

With a proper bias of the sample (up to 50 eV), true secondaries with low energies are allowed or not to escape the surface and two coefficents can be measured, the true secondary electron emission (δ= Is/Ip) and the backscattered coefficient (η= Ib/Ip). The "total secondary emission" σ is computed as: $\sigma = \delta + \eta$.

Facilities and experience should also allow:

Measurement of secondary electron emission properties of spacecraft dielectric materials:

- Dependence of total secondary emission yield on primary energy, incident and emission angle
- Dependence true secondary emission yield on primary energy, incident and emission angle
- Energy distribution (spectra) of secondary emission

Study of dependence of secondary emission properties on:

- air exposure
- electron bombardment (conditioning: relevant for space dose effects)
- ion bombardment (conditioning: as above)
- heat treatment (relevant to contamination effects)

Analysis of the relation of secondary emission properties with:

- surface chemical composition
- surface roughness (relevant to ATOX influence)
- surface work function (academic interest)

Surface conditioning:

The total dose effect from electrons, ions or photons has been found to decrease the secondary electron yield and to result in a value of σm or δm which can be even lower than the measured value for the base material. The physical process, which causes this reduction of σm is related to the surface ion desorption. Electron conditioning treatment can be performed by use of electrons of 500 eV, 1μA/mm^2 for variable duration.

Parallel Programmes

Outside Europe, major US research institutions dealing with spacecraft charging are carrying out a program very similar to this project. In the frame of the Space Environment and Effects Program, two actions similar to this study have started:

A data base (Satellite Contamination and Materials Outgassing Knowledgebase) has been attributed to the Bob Wood Aerospace Consulting Services, Inc., and an experimental program for the measurement of Charge Storage Decay Time and Resistivity of Spacecraft Insulators. The program is conducted by the Utah State University. Nearly 63 materials that are either in use today or provide a promising future in tomorrow's spacecraft design have been identified in this program.

Conclusion

The European Space Agency initiated and funded an activity to characterise the physical material properties needed for the modelling of material-plasma interaction. The subsequent contract has a nominal duration of 2 years. It is expected that by the end of this contract relevant properties for a large amount of materials, as well as the impact of ageing and space exposure on these properties will be assessed and integrated into a database.