
Physics of Dielectric Breakdown Revealed by Low-Frequency Noise Spectroscopy

A Data Management Plan created using DMPonline.be

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Project abstract:

Dielectric breakdown is the physical phenomenon wherein a dielectric material loses its insulating properties, due to a prolonged exposure to an applied stress, after which it eventually starts to conduct electricity. It is one of the main failure mechanisms of Back End Of Line (BEOL) dielectrics in interconnect systems, giving rise to several reliability issues for semiconductor devices that are expected to work for at least ten years under operating or use conditions. Traditional dielectric reliability methodologies, such as e.g. Time-Dependent Dielectric Breakdown (TDDB), are based on accelerated testing, where the dielectric is put under higher stress compared to operating conditions, until it breaks down. The associated breakdown voltage as well as the time needed to break down, are used to extrapolate the dielectric lifetime to operating conditions, using an empirical model (e.g. the power law model). Limitations of this conventional approach are that it is time-consuming, destructive, and the acquired physical insight, concerning the physics of dielectric breakdown, is limited. In this work, we therefore explore the potentiality of the Low Frequency Noise (LFN) technique, as an alternative way of assessing the dielectric reliability as well as predicting the dielectric lifetime. In LFN, the statistical distribution of the dielectric leakage current fluctuations, is studied in the frequency domain in the form of a Power Spectral Density (PSD). The PSD is a measure of the trap density of the dielectric, which allows to quickly probe the defectivity of the dielectric, and thus also its lifetime. LFN measurements are non-destructive and fast compared to TDDB, and have the potential to provide additional physical insights into the failure mechanisms of dielectric materials.

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Application DMP

Questionnaire

Describe the datatypes (surveys, sequences, manuscripts, objects ...) the research will collect and/or generate and /or (re)use. (use up to 700 characters)

- During this project experimental 1/f noise data will be collected, by performing electrical characterization measurements on dielectric materials used in electronic chips.
- The generated output files from the experiments are of the type .csv and/or .mdm. Each file contains a header with all the relevant information regarding the experiment, which is followed by two data columns, one representing the 'time' (or 'frequency') and the other one representing the 'current' (or the 'noise power').
- This data is analyzed with data analysis software (e.g. Python), to make meaningful figures such as line plots, histograms, etc. These figures are used in PowerPoint presentations (.pptx), and in PDFs when writing a manuscript for a conference or a journal, for disseminating the acquired results.

Specify in which way the following provisions are in place in order to preserve the data during and at least 5 years after the end of the research? Motivate your answer. (use up to 700 characters)

- The designated responsible people for proper follow-up and preservation of the collected data during this project are Davide Tierno ('Researcher' at imec, email: davide.tierno@imec.be), Kristof Croes ('Scientific Director' at imec, email: kristof.croes@imec.be), and Valeri Afanasiev ('Professor' at KU Leuven, email: valeri.afanasiev@kuleuven.be), which are the supervisors of the FWO fellow. They can be contacted in case of any questions regarding accessing the data collected during the project.
- The collected data is stored on the SharePoint and OneDrive databases of imec. These databases have unlimited storage capacity and there is no storage time limit. The FWO fellow has no upper limit regarding how much data can be collected, and the collected data will be stored on the imec databases forever. Upon request, which should be approved by the designated people above, the data can be requested/accessed at any point in time, both during the project and afterwards.

What's the reason why you wish to deviate from the principle of preservation of data and of the minimum preservation term of 5 years? (max. 700 characters)

We do not want to deviate from this principle.

Are there issues concerning research data indicated in the ethics questionnaire of this application form? Which specific security measures do those data require? (use up to 700 characters)

There are no personal data regarding human participants, and thus no issues concerning this aspect. All collected data are coming from materials used in electronic chip processing/fabrication.

Which other issues related to the data management are relevant to mention? (use up to 700 characters)

There are no other issues regarding the data management of this project.

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FWO DMP (Flemish Standard DMP)

1. Research Data Summary

List and describe all datasets or research materials that you plan to generate/collect or reuse during your research project. For each dataset or data type (observational, experimental etc.), provide a short name & description (sufficient for yourself to know what data it is about), indicate whether the data are newly generated/collected or reused, digital or physical, also indicate the type of the data (the kind of content), its technical format (file extension), and an estimate of the upper limit of the volume of the data.

				Only for digital data	Only for digital data	Only for digital data	Only for physical data
Dataset Name	Description	New or reused	Digital or Physical	Digital Data Type	Digital Data format	Digital data volume (MB/GB/TB)	Physical volume
		<i>Please choose from the following options:</i> <ul style="list-style-type: none"> • Generate new data • Reuse existing data 	<i>Please choose from the following options:</i> <ul style="list-style-type: none"> • Digital • Physical 	<i>Please choose from the following options:</i> <ul style="list-style-type: none"> • Observational • Experimental • Compiled/aggregated data • Simulation data • Software • Other • NA 	<i>Please choose from the following options:</i> <ul style="list-style-type: none"> • .por, • .xml, • .tab, • .csv,.pdf, • .txt, .rtf, • .dwg, • .gml, ... • NA 	<i>Please choose from the following options:</i> <ul style="list-style-type: none"> • <100MB • <1GB • <100GB • <1TB • <5TB • <10TB • <50TB • >50TB • NA 	
Current	The electrical current as a function of the applied voltage	Generate new data	Digital	Experimental	.csv .mdm	<1TB	NA
RTN	The current as a function of time, at a given voltage	Generate new data	Digital	Experimental	.csv .mdm	<1TB	NA
PSD	The noise spectrum calculated from the RTN	Generate new data	Digital	Experimental	.csv .mdm	<1TB	NA
MIM	The material samples are metal-insulator-metal (MIM) capacitors	Generate new data	Physical	NA	NA	NA	The samples are 300 mm wafers, ready to be used and to be characterized.
Data analysis and postprocessing	The experimental data files are read into Python and then analyzed to make meaning figures such as line plots, histograms, etc. These figures are used to show in presentations and are published in research articles, when disseminating the results.	Generate new data	Digital	Software	.pptx, .pdf, .docx	<100MB	NA

If you reuse existing data, please specify the source, preferably by using a persistent identifier (e.g. DOI, Handle, URL etc.) per dataset or data type:

We only use newly generated data.

Are there any ethical issues concerning the creation and/or use of the data (e.g. experiments on humans or animals, dual use)? Describe these issues in the comment section. Please refer to specific datasets or data types when appropriate.

- No

There are no issues regarding this aspect.

Will you process personal data? If so, briefly describe the kind of personal data you will use in the comment section. Please refer to specific datasets or data types when appropriate.

- No

There is no personal data processed in this project.

Does your work have potential for commercial valorization (e.g. tech transfer, for example spin-offs, commercial exploitation, ...)? If so, please comment per dataset or data type where appropriate.

- Yes

The collected experimental 1/f noise data is used to obtain more insights into the degradation mechanisms occurring in dielectric materials used in state-of-the-art electronic chips. We compare the noise data one-to-one with other conventionally used techniques, so as to provide a new failure detection method that assesses the materials in an alternative and complementary way, yielding more physical insights, in a shorter amount of time compared to other techniques, and without completely destroying the studied samples. Our developed method could potentially be adopted by semiconductor companies (cf. imec's industrial partners), working on materials reliability and R&D regarding chip processing/fabrication.

Do existing 3rd party agreements restrict exploitation or dissemination of the data you (re)use (e.g. Material/Data transfer agreements/ research collaboration agreements)? If so, please explain in the comment section to what data they relate and what restrictions are in place.

- No

There are no issues regarding this aspect. The project is carried out using data collected at imec and on samples fabricated at imec, making 3rd party agreements irrelevant.

Are there any other legal issues, such as intellectual property rights and ownership, to be managed related to the data you (re)use? If so, please explain in the comment section to what data they relate and which restrictions will be asserted.

- No

There are no issues regarding this aspect. In a later stage, when a fully consistent 1/f noise detection method has been developed, a patent will be filed.

2. Documentation and Metadata

Clearly describe what approach will be followed to capture the accompanying information necessary to keep data understandable and usable,

for yourself and others, now and in the future (e.g., in terms of documentation levels and types required, procedures used, Electronic Lab Notebooks, README.txt files, Codebook.tsv etc. where this information is recorded).

The collected data is stored on the imec databases:

- The datafiles are classified according to the year or semester in which they were collected, making it possible to find everything back in chronological order.
- For a given material sample and/or experiment, the data is stored inside a folder with a path of the form: '\Year-Semester/WaferType/WaferCode/DateOfExperiment/NameOfExperiment/BiasConditions/Temperature/TypeOfNoise'. This way, the data of a given experiment can be easily recovered by going back to the year/semester in which it was collected (e.g. 2024), then we choose the type of wafer (e.g. single layer or multilayer), then the wafer code (e.g. D16 - 20 nm SiO₂), then the date of the experiment (e.g. March 1, 2024), then the name of the experiment (e.g. 'low-to-high voltage sweep'), followed by the experimental conditions (e.g. voltage bias and applied temperature) and the type of noise (e.g. LFN or RTN).
- In addition to the file structuring/classification of above, each datafile contains an extensive header with detailed information regarding the type of experiment, experimental conditions, the date of the experiment and other relevant experimental details about both the studied material samples and the used experimental set-up and associated software.
- The filetypes are .csv and .mdm, which can be read/analyzed with any data analysis software.

Will a metadata standard be used to make it easier to find and reuse the data? If so, please specify (where appropriate per dataset or data type) which metadata standard will be used. If not, please specify (where appropriate per dataset or data type) which metadata will be created to make the data easier to find and reuse.

- Yes

-The standard for both the data files (i.e. the numerical data) as well as the file storage/structuring/classification (i.e. the precise file location) is according to the software program of the Advanced Low-Frequency Noise Analyzer (ALFNA) of Keysight Technologies (i.e. the software and the experimental set-up used for the data collection). The classification and storage according to wafer number, date of experiment, applied temperature, etc., is a common procedure for Keysight's commercial noise instrumentation and associated wafer probers (international standard for wafer probers and ALFNA software).

-In addition to the above, the extensive header in each datafile contains detailed information regarding every aspect of the experiment. This header as well as the associated numerical data, is structured according to the international standard of wafer probers and ALFNA software.

3. Data storage & back-up during the research project

Where will the data be stored?

All collected data is stored on the online database of imec (SharePoint/OneDrive), which has unlimited storage capacity, without any storage time limit.

How will the data be backed up?

All collected data is stored on the online database of imec (SharePoint/OneDrive), which has unlimited storage capacity, without any storage time limit. The data can be requested/accessed at any time, now or in the future, as it will remain on the online imec database forever.

Is there currently sufficient storage & backup capacity during the project? If yes, specify concisely.

If no or insufficient storage or backup capacities are available, then explain how this will be taken care of.

- Yes

The imec database on which the collected data is stored, has unlimited storage capacity, and no storage time limit.

How will you ensure that the data are securely stored and not accessed or modified by unauthorized persons?

The collected data are stored on the online databases of imec (SharePoint/OneDrive). This database can only be accessed internally (only imec employees), and even within imec the access is highly restricted to scientists working in the same research group as the FWO fellow (in principle, only the supervisors of the FWO fellow have access to these databases). For non-imec individuals, only those with granted access (approved by Davide Tierno, Kristof Croes, Valeri Afanasiev and imec), can access and view the data stored on the database.

What are the expected costs for data storage and backup during the research project? How will these costs be covered?

All storage costs are covered by imec, both during and after the project. There are no additional costs.

4. Data preservation after the end of the research project

Which data will be retained for at least five years (or longer, in agreement with other retention policies that are applicable) after the end of the project? In case some data cannot be preserved, clearly state the reasons for this (e.g. legal or contractual restrictions, storage/budget issues, institutional policies...).

All data will be stored on the imec online database, forever. It can be accessed at any time in the future.

Where will these data be archived (stored and curated for the long-term)?

All data will be stored on the imec online database, forever, in the same location.

What are the expected costs for data preservation during the expected retention period? How will these costs be covered?

All storage costs are covered by imec, both during and after the project. There are no additional costs.

5. Data sharing and reuse

Will the data (or part of the data) be made available for reuse after/during the project? In the comment section please explain per dataset or data type which data will be made available.

- No (closed access)

-The data will always be available on the imec database, thus it can always be accessed and reused at any point in time, in the future.

-We do not make the data publicly available. Individuals can always request the data, e.g. after dissemination of the results in a publication.

If access is restricted, please specify who will be able to access the data and under what conditions.

Anyone can access the data upon reasonable request (including non-imec individuals). This request, however, has to be evaluated and approved by the designated responsible people (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec).

Are there any factors that restrict or prevent the sharing of (some of) the data (e.g. as defined in an agreement with a 3rd party, legal restrictions)? Please explain in the comment section per dataset or data type where appropriate.

- Yes, Privacy aspects
- Yes, Intellectual Property Rights

The data is used to study degradation phenomena in electronic chips, with the intention of developing a new methodology, which might

involve the filing of patents in a later stage. We thus never make the data publicly available. It can only be accessed upon reasonable request, and after approval of this request by the designated responsible people (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec).

Where will the data be made available? If already known, please provide a repository per dataset or data type.

We never make the data publicly available. It can only be accessed upon reasonable request, and after approval of this request by the designated responsible people (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec).

When will the data be made available?

We never make the data publicly available. It can only be accessed upon reasonable request, and after approval of this request by the designated responsible people (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec).

Which data usage licenses are you going to provide? If none, please explain why.

We never make the data publicly available. It can only be accessed upon reasonable request, and after approval of this request by the designated responsible people (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec). Thus, the data can only be accessed and 'viewed', but it can never be legally reused, under any circumstance.

Do you intend to add a PID/DOI/accession number to your dataset(s)? If already available, you have the option to provide it in the comment section.

- No

We never make the data publicly available.

What are the expected costs for data sharing? How will these costs be covered?

We never make the data publicly available. It can only be accessed upon reasonable request, and after approval of this request by the designated responsible people (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec). There are no costs involved in the action of data sharing.

6. Responsibilities

Who will manage data documentation and metadata during the research project?

The FWO fellow manages the data.

Who will manage data storage and backup during the research project?

The FWO fellow manages the data storage/backup.

Who will manage data preservation and sharing?

The FWO fellow and his supervisors (Davide Tierno, Kristof Croes, Valeri Afanasiev and imec).

Who will update and implement this DMP?

The FWO fellow updates the DMP.

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GDPR

GDPR

Have you registered personal data processing activities for this project?

- Not applicable

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DPIA

DPIA

Have you performed a DPIA for the personal data processing activities for this project?

- Not applicable