Automated Analysis of Vacuum Processes Using Artificial Intelligence

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Vacuum deposition processes are being equipped with an ever-expanding array of sensors to gain more control over the process conditions. Unfortunately, this often presents the machine operator with too much data to be able to draw clear insights into the performance of the process. Machine learning algorithms are a powerful tool for analyzing large and complex sets of data and have been at the forefront of a revolution artificial intelligence.
These techniques are ideally suited for analyzing problems encountered in vacuum processes, which are often expressed as “classification problems”, i.e., identifying if a leak is present in the system or not. In particular, they can be applied to the automated analysis of optical emission spectra (OES) of plasma. OES provides critical information on the state or condition of a process. However, expert knowledge is often required to be able to interpret the data, and in some cases, the spectra are too complex to extract key information using the human eye alone. This paper will present the application of a machine learning A.I. to the automated analysis of magnetron and remote plasma OES data. Examples include leak detection, organic contamination detection and the identification of organic molecules from cracking patterns.

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Note from Managing Editor: We are delighted to share with the readers of the Bulletin some of the interesting Powerpoint Presentations from past TechCons. We hope you find them as interesting as we do.

Sue Taube/Managing Editor

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AI and Machine Learning

- Artificial Intelligence, powered by machine learning, has revolutionised the way we use data.

- Our modern world is run using A.I. (for better or worse!) with applications in healthcare, advertising, transport and security

Traditional approach, cancer screening

Costly / Invasive scan

Expert data interpretation

Tumour

No Tumour

Pattern recognition for predictive, preventive, and personalized medicine in cancer

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Artificial Intelligence, powered by machine learning, has revolutionised the way we use data.

Our modern world is run using AI (for better or worse!) with applications in healthcare, advertising, transport and security.

**Machine Learning, cancer screening**

- Biomarkers regularly monitored
- Machine learning pattern recognition
- Tumour
- No Tumour

Artificial Intelligence, powered by machine learning, has revolutionised the way we use data.

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**Sensing for Vacuum Processes**

Where are we now?

- RF analysers
- Residual gases
- Temperature
- Plasma energy
- Plasma emission monitoring

Applied Materials are using ML to automatically detect wafer defects.

Applied Materials ExtractAI

1. Unsupervised Data: Use DEER to rapidly generate database of potential defects
2. Classification & Training: Use DEER/Mozaic to train ExtractAI to classify defects and noise
3. Inference: Engage with ExtractAI now to automatically recognize specific defects across the wafer map
AI and Machine Learning For Vacuum Processes

- ML methods and tools are developed to the extent that they can be "democratised"
- How can we exploit this technology within our industry

Chamber condition
Process state
Leak detection
Vacuum quality
Materials properties

AI based leak detection

- Current methods of leak detection are slow and invasive
- Either base pressure is reached (e.g. 1E-5 mbar) and residual gases are analysed
- Or a rate-of-rise test is performed at base pressure
- Can we use gas partial pressure data to train an AI to identify leaks
  - much faster?
  - without intervention?

AI based leak detection
Training data

- Optix used to record partial pressures during pumpdown
- A small turbo pumped system was used for speed of data collection

- Variation of leak rate
- Time exposed to atmosphere
- Recording of total pressure
- Partial pressure of N₂, O, OH, H, Ar, CO₂
- 3700 data sets
AUTOMATED ANALYSIS OF VACUUM PROCESSES USING ARTIFICIAL INTELLIGENCE

**2D representation of SVM**
- No leak
- Leak
- Training data

**3D representation of SVM**
- Pressure
- OH
- N2

**Real SVM is 7th dimensional!**
- Pressure
- OH
- N2
**AI based leak detection**

**SVM algorithm**

**Training data**

<table>
<thead>
<tr>
<th>N2</th>
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<tbody>
<tr>
<td>N2+</td>
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<tr>
<td>CO2</td>
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<td>H</td>
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</tbody>
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**AI Leak Checker**

[7-n Dimensional SVM]

**Result**

Leak or No Leak

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**AI based leak detection**

**Validation**

- Chamber volume 0.1 m$^3$
- Pumping speed 1000 l/s (nominal)

- 4 pumping data sets
- 2 with leaks
- 2 without leaks

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**Chamber leaks**

- AI leak checker evaluated every 5 seconds
- Both instances of the chamber leak were identified
AUTOMATED ANALYSIS OF VACUUM PROCESSES USING ARTIFICIAL INTELLIGENCE

CONTRIBUTED PRESENTATION
IN POWERPOINT FORMAT
FROM THE 2021 TECHCON

AI based leak detection Validation

Chamber leak-tight

- Chamber determined leak-tight in less than 10 minutes pumping time
- Leak checking algorithm successful below 3E-2 mbar

AI based analysis of OES

- Confusing multiple identification is very common using current approaches
- Large data sets are difficult to quickly gather useful data from

AI based analysis of OES

- Spectra recorded from Optix OES based gas sensor
- Only knowledge given to AI is the emission reference library
- Design an AI to automate analysis
  - Extract trends
  - Identify gases / species

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AI based analysis of OES

Emission libraries

Fitting

Spectra time series

Gases identified and isolated

Clustering

- Time series clustering

- Assumption: All emission lines of one gas will have the same dynamic behaviour
- Use an AI to "cluster" emission lines into similar dynamic behaviours
- AI has separated the 146 emission lines into 7 groups or "clusters"
- Each cluster should represent a different gas or feature

Reduction of 1596 wavelengths to 146

- Separate the interesting data from the noise
- 3D peak finder

Exploit similarity of gases
- Simplify data
- Assist with identification
AUTOMATED ANALYSIS OF VACUUM PROCESSES USING ARTIFICIAL INTELLIGENCE

AI based analysis of OES - Emission line fitting

- Emission line fitting

Comparison with emission library

% fit

Time series cluster

Corresponding emission lines

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AI based analysis of OES - Emission line fitting

- Emission line fitting

Noise

Ar (80%)

CO₂ (60%)

N₂ (60%)

Cr (3%)

Cr (4%)

ArII (6%)

Each cluster identified with a “confidence” %

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Areas for exploration

• Combining different sensors

• Can we determine deposited material properties in real time using ML?

Chamber condition

Process state

Leak detection

Vacuum quality

Materials properties
Joe holds a PhD in Mechanical Engineering from the University of Strathclyde, where he researched feedback control algorithm design with applications in reactive sputtering. Since joining Gencoa as a Research and Development Engineer in 2012 he has been responsible for the development of the company’s sensing and control products. This includes bringing to the market Gencoa’s Optix gas sensor and authoring of patented algorithms for automation of sputter processes. Joe is currently working on the application of machine learning and AI to vacuum process control and is the industrial supervisor for a PhD research project on this topic.