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In-situ Thin Films Process Control

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Feature Article
特集論文

In-situ Thin Films Process Control

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ABSTRACT

The need for in-situ process control led to the creation of SOFIE Instruments company. Sofie was founded in 1983 as a spin-off from two French organizations, the University of Orsay and CIT Alcatel (Semiconductor Division). SOFIE's primary activity consists of the study, development and manufacturing of instruments for in-situ thin film process control and analysis utilizing techniques such as Optical Emission Spectroscopy, Interferometry and Imaging, Ellipsometry, and Langmuir Probes.

Sofie products are constantly evolving, driven by the innovations of their engineers working in collaboration with customers. The new ideas developed at Sofie on sensors and analytical methods are protected by numerous international patents. The competitive edge of our products is based on the originality of the architecture, smart sensor technology, analytical methodology, and unique signal processing.

1. ARCHITECTURE

In order to meet different requirements that often change very quickly, our systems are based on a flexible and modular architecture consisting of three levels.

(1) Level 1

State of the art sensors including monochromators, spectrographs, laser or white light interferometers, an in-situ ellipsometer, Langmuir probes, a mass spectrometer, particle counter, DC Bias and RF electrical analysers, and temperature monitors interface with process chambers to measure a wide variety of parameters for controlling processes and determining plasma characteristics.

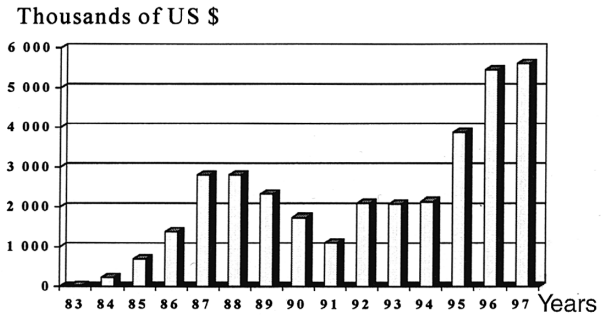


Fig.1 Turnover history of SOFIE

In-situ 薄膜プロセス制御

1983年に設立されたSOFIEは, 優れた光学技術をベースに, 各種の半導体プロセス用とくに薄膜関連の計測制御システムの開発・製造を行っている。当社の製品の競争力は, 独創的なアーキテクチュア, スマートなセンシング技術 , ユニークな信号処理などにささえられている。**図1**に当社の売上高推移を示す。

1. アーキテクチャー

半導体業界の多彩で激しい変化に対応するため, SOFIEの計測・制御システムは, フレキシブルなモジュール方式の3段階のアーキテクチュアから構築される。

(1)レベル1

分光器 , エリプソメータ , 質量分析計などの分析機器が各々独立にチャンバに接続され , プロセスの計測や管理を行う。

(2)レベル2

センサの出力はパソコンをベースとしたサブステーションに入力され,ここで信号処理や演算処理を行い, プロ

(2) Level 2

The second level is composed of PC based substations communicating with the sensors through acquisition boards. One station can be connected to up to two sensors and any of the variety of sensors can be utilized.

Each station performs such tasks as enhanced numerical filtering, derivative calculation, local data base support, and Fourier transformations. For process control functions there is a remote control link from each substation to the equipment.

(3) Level 3

Level 3 involves overall system control and coordination utilizing a supervisor computer. This is necessary for complex multichamber and multisensor applications. In a simple one chamber application, user interface functions can be controlled directly at the sub-station level. But in complex environments where several stations have to work together, a supervisor must exist to provide a common user interface and data base support for a group of stations. The supervisor is linked to the stations through a local area network. It also supports a direct Secs II communications link to the equipment. Overall depending on which level of archetecture is used, there will be different access to the equipment.

1.2 Configuration

The selection of a configuration, either a stand alone unit, (one station with up to two sensors), multichamber, or cluster tool configuration depends on the application.

Consideration must be given to :

- the number of stations
- the type of sensors required
- the type of communication protocol

In addition, the communication interface with the tool is crucial for accurate process control. Our software provides protocols to communicate with most of the equipment manufacturers present on the market. SOFIE has the ability to quickly adapt to any new tool if the communication protocol is provided.

1.3 Benefits of design

- A high level of flexibility is possible on each level of architecture (sensors, network, user interface or communication protocols). This provides a wide variety of solutions for any application.
- The ability to synchronize different stations on the same chamber. The system provides a common data base to store information on runs from different chambers which is very useful for comparison.
- The network based architecture allows parameter passing from one sub-station to another sub-station. The value of a measurement made in one chamber of a cluster tool can be sent to another sub-station and used by another endpoint detector in a different chamber on the same cluster tool.

Figur 2 shows the architecter for a cluster tool with four chambers.

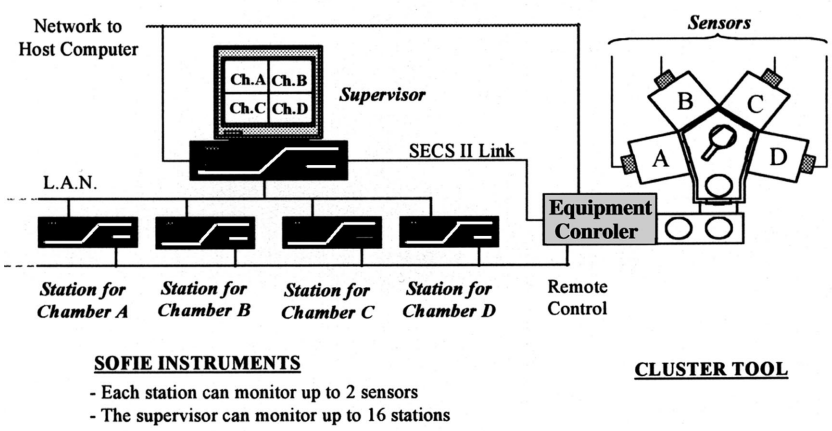


Fig.2 Architecture for a cluster tool with four chambers

セス機器に制御信号を送る。各ステーションには最大 2 個のセンサが結合できる。

(3)レベル 3

マルチチャンバ, マルチセンサからなる複雑なプロセスでは, 統合コンピュータを使って総合的に複雑な計測制御を行う。ステーション群と統合コンピュータの間は LAN を通じて通信される。

1.2 コンフィギュレーション

計測･制御システムとしてスタンドアローン型か , マルチ・チャンバまたはクラスタ・ツール型のいずれを選ぶかは , ステーション数 , センサの種類 , 通信プロトコルの種類などを考慮して決定される。当社のシステムは , 各種の設備機器 , 通信システムに素早く対応できる。

1.3 システム構築上の利点

・自由度が高く , あらゆる用途に対して多様なシステムを提供できる。
・データベースが共通化されており , チャンバ間のプロセス情報を共有できる。
・システム全体がネットワークで結ばれておりサブステーション間で情報交換が自由にできる。
例えば , 終点検出器の情報を異なるチャンバ間で共有することができる。

図 2 に 4 つのチャンバを持ったクラスタ・ツール用アーキテクチャーを示す。

2. ORIGINAL SENSORS

A key part of the system is the availability of a variety of smart sensors each designed to monitor specific process steps and critical parameters in the same or different chambers of a cluster tool.

2.1 Optical Emission Spectroscopy (OES)

The plasma light provides a wealth of information about the etch state, chamber properties, and species reactivity. Usually, this information is easily exploitable. One way to use this information is in determining the endpoint of an etch process. It relies on the simple fact that when one etches through a layer and hits a chemically different underlayer, the plasma composition, and therefore the emission spectrum, changes as the new layer is etched and appears in the plasma .

<Benefits of the SOFIE OES system>

Our OES systems allow the ability to synchronize low and high resolution monochromators, in order o have a vision of the full spectrum and simultaneously to focus on one specific part chosen by the user with higher resolution.

2.2 Interferometry and Imaging

Interferometry is a powerful technique consisting of illumination of the surface and measuring the reflected intensity from several layers.This sensor allows the determination of the etch or deposition rate, the thickness, and the selectivity. Both monochromatic, for differential measurements, and spectroscopic, for absolute measurements of the thickness are available.

<Benefits of the SOFIE Interferometric system>

For complicated structure with small critical dimensions imaging capability is necessary. We provide a Sofie patented camera combining a compact interferometer and a CCD sensor for wafer observation and spot alignement. Attached to a motorized X-Y table, this system allows patterns recognition. Bringing a compact optical head that includes the interferometer, CCD imaging, and positioning stages for pattern recognition all together in one very compact package.

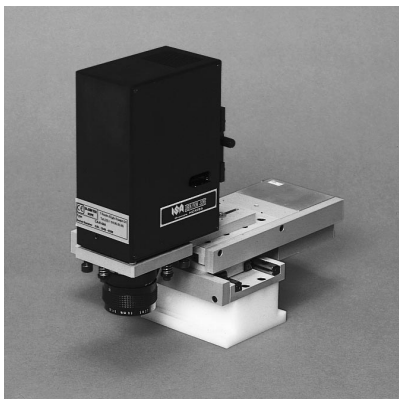


Fig.3 The SOFIE Interferometric system

Figure 3 shows the SOFIE Interferometric system.

2.3 Langmuir Probe

A Langmuir probe system consists of a thin conductive wire inserted into the plasma. By applying a voltage ramp to this wire an I(V) characteristic is obtained. Then, by using a suitable theory, the following plasma parameters can be determined : ion density, electron density, floating potential, plasma potential, electron energy distribution function (EEDF) and temperature. The spatial distribution of the parameters can be obtained by scanning the probe inside the chamber.

<Benefits of the SOFIE Langmuir Probe>

A recently developed SOFIE product combines the Langmuir probe with the Optical Emission Spectroscopy on a single sensor. This association allows the user to synchronize the two measurements in order to have the spatial distribution of the parameters described above, as well as the spectral distribution of a line to get, for instance, more information on the uniformity.

2.4 Electrical Measurements and DC Bias Voltage

Etch an deposition plasmas are largely determined by electrical variables like RF power, power distribution etc. Knowledge of electrical properties is therefore essential to understanding plasma characteristics and can be useful for

２．独自のセンサ群

SOFIE の計測･制御システムの特徴は独自のインテリジェント・センサを幅広く活用できる点にある。

2.1 発光分光分析装置(OES)

プラズマからは , エッチングの状況 , チャンバの特性 , フラッグメントの反応性など様々な情報が得られる。エッチング工程におけるエンドポイント検出はその典型例である。

＜ OES の特長＞

高･低二つの分解能の分光器を組み合わせることにより , スペクトル全体および任意の特定スペクトルの両方を同時に捕らえることができる。

2.2 干渉計と画像作成機能

干渉計によりエッチング速度 , デポジッション速度 , 膜厚 , 選択性の判定などができる。

＜干渉計の特長＞

小型の干渉計と CCD カメラを組み合わせにより , ウエハの観察や微細なアライメントが可能となる。
干渉計 , CCD カメラ , X-Y ステージがコンパクトにまとめられている。（**図３**）

process monitoring. One of these variables is the DC voltage (DC Bias) building up between the polarized RF electrode and the mass. Its importance depends on the process under consideration. In physical etch processes by ion impact for instance, this parameter will largely determine etch properties since the DC Bias creates the accelerating tension for the ions.

3. SIGNAL PROCESSING

Several trends in the semiconductor market are driving the need to improve signal processing : the need to increasing yields in wafer manufacturing, the need to produce small critical dimensions (which leads to a deterioration of the signal to noise ratio), and short process times (the system then has less data to fit the phenomenom with the suitable theory and detect the endpoint).

3.1 Endpoint algorithms

Accurate endpointing represents a main customer goal. It consists of finding a special signal variation pattern during the run analysis using a defined model in order to immediately stop the process. This endpoint detection must be very reliable, must allow parameter tuning to eliminate bad patterns and to guarantee to meet the needs of manufacturing. With the constant development of new technologies, endpoint methods are continuously updated to combine DSP numerical techniques, cross sampling methods, run to run variations, and improved detection sensitivity even inside noisy signals. Several endpoint methods can also be combined for enhanced endpoint detection.

3.2 Reprocessing Cability

Process application engineers are under enormous pressure to shorten time to production, in addition they must minimize the number of development wafers used. The reprocessing software embedded in the family of SOFIE instruments permits the process engineers to replay a previous run in an accelerated mode in order to simulate and verify all signal analysis and all parameter settings without processing additional wafers. It is even possible to do reprocessing analysis outside of the clean room and to utilize the knowledge of our customer support team by sending files on internet to SOFIE.

3.3 Alarm management

In addition to endpointing, SOFIE systems are capable of detecting other process events or wrong process conditions which could lead to an endpoint miss and the resultant scrapping or reworking of production wafers. Our powerful alarm methods can be selected to analyse and detect process problems before wafers are ruined or require costly rework. Depending on the alarm condition found, appropriate actions can be taken for example: immediate stop, continuing to a default time, and database warning.

Table 1 shows available sensors for in-situ process control product ÅgDIGIFAMILYÅh .

4. CONCLUSIONS

The family of SOFIE products offers the customer state of the art instrumentation for semiconductor process control. We are unsurpassed in the flexibility and innovation in all aspects of our design. Whether it's the instruments, sensors, software, or the open architecture of multichamber control, our solutions represent the cutting edge of process control technology. Just as important as our products are the people of SOFIE and their commitment to being the best in the industry . We provide a level of customer support that consistently wins the appreciation of our customers. The passion of the people at SOFIE for being the best in the industry is experienced by every customer we serve.

2.3 ラングミュア・プローブ

チャンバ内にラングミュア・プローブ挿入し , イオン・電子密度 , 浮遊電位 , 電子エネルギーの分布 (EEDF)などを計測する。

＜ラングミュア・プローブの特長＞

ラングミュア・プローブと発光分光分析計とを組み合わせると , プロセスのスペクトルの空間分布が測定でき , 得られる情報が格段に増える。

2.4 電気的測定と直流バイアス電圧

プラズマエッチング･デポジッションの状態は, RF強度や直流バイアスなどの電気条件によって左右されるため , これらの計測･制御が重要となる。

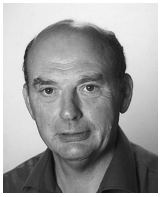
表１に当社のその場型 薄膜プロセス制御用センサ(DIGIFAMILY)の測定原理とキーテクノロジーをまとめた。

３．信号処理

生産プロセス側からは , 歩留まり向上 , より微細な加工 , サイクル・タイムの短縮など , 計測面から見ると厳しい様々な要望が出されている。

Table 1 Abvailable sensors for in-situ process control product DIGIFAMILY

PRODUCTS	PRINCIPLE	KEY TECHNOLOGIES
DIGISEM	Optical emission spectroscopy Applications : **Endpoint detection** Uniformity control Plasma Diagnosis Contamination Control Chamber cleaning control	Signal processing Endpoint algorithms Synchronization between 2 monochromators Embedded software elasticity allowing the same tool from R&D to full manufactoring automation
DIGILEM	Laser interferometry : End point detection Layer thickness monotoring Remaining layer thickness Etch and deposition rates Trench depth Selectivity	Signal processing Endpoint algorithms Alarm management Interferometry and Imaging : Patented camera including a CCD sensor for wafer observation and pattern recognition
DIGIPROBE	Langmuir probe (electrostatic probing) : **Ion and electron density** Floating potential Plasma potential Electrons energy distribution Function (EEDF) Electron temperature Plasma uniformity	Signal processing fast acquisition Cleaning capability Radio frequency current measurement
DIGITOM	Spectroscopic interferometry : Absolute thickness in-situ measurement	Signal processing Pattern recognition Layer optical modelling The determined thickness can be sent to another chamber and used for endpointing another step Avoid off-line measurements
DIGIBIAS	DC bias, RF or peak to peak voltage Applications : Chamber contamination Wet clean monitoring	
DIGITWIN	Combined OES and Interferometry : **Endpoint detection** Etch and deposition rates Plasmas diagnosis, etc...	Signal processing Endpoint algorithms Endpoint conditions associating two different sensors
	Combined OES and Langmuir probe	local plasma diagnosis by simultaneous optical and electrical measurements
MULTISEM	Multisensors and Multichambers platform	Real-time supervision of all sensors, all chambers PC and Network based architecture Total flexibility allowing combination of up to 16 different sensors



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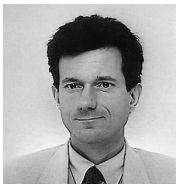

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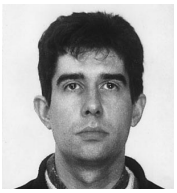

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3.1 終点の検出

正確な終点検出は不良パターン排除のためにも重要である。DSP(Digital Signal Processor)を使った数値計算, クロス・サンプリング, 工程間変動, 信号対雑音比の改善など, 最新の手法が試みられている。複数の終点検出法を組み合わせることも高精度化には有効である。

3.2 プロセスの再生

開発段階の時間短縮とウエハの削減が絶えず要求されている。本計測・制御システムは, ウエハを改めて加工しなくても, 前の工程を高速で再生し, 信号を解析し, 全ての設定条件をシミュレート, 実証することができる。さらに, 顧客からはインターネットを介して当社の支援を受けることもできる。

3.3 アラーム管理

本システムは, 終点検出だけでなく各種の異常を検出し, 警報することができる。アラーム内容を解析し, 内容次第で即時停止, ディフォールトタイムまで続行, 警告の記録など的確な対応をとることができる。

4．結論

SOFIE の製品は, センサ, ソフトウエア, アーキテクチャいずれもフレキシブルで最先端を行く。当社の従業員が常に業界 No.1 でありたいと願う熱意は, 我々のお客様全てにお感じいただけるものと自負している。

（抄訳:半導体システム企画開発部　永井良典）

※本論文の著者のお一人 Dr. CANTELOUP は 1998 年 6 月 20 日に逝去されました。謹んで哀悼の意を表します。