Overview of Magnetron Sputtering System (DaON 1000S) by Murtaza Saleem
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What is a Plasma?

• States of Matter (Ancient View)
  – Earth, Water, Wind, Fire
• States of Matter (Modern View)
  – Solid, Liquid, Gas, Plasma
Plasma

- Ar ions are accelerated towards the target for sputtering
- Release of secondary electrons

- Sufficiently low pressure
  - So electrons achieve necessary energy before collisions
  - Too low pressure gives too few collisions to sustain the plasma

The glow comes from de-excitation of atoms after collision with electrons that has too low energy for complete ionization
Different plasma discharge regimes

Voltage-Current Characteristic of the DC Low Pressure Electrical Discharge Tube

- **Dark Discharge**
  - Townsend Regime
  - Corona
  - Breakdown Voltage
- **Glow Discharge**
  - Normal Glow
  - Abnormal Glow
- **Arc**
  - Glow-to-Arc Transition
  - Non-Thermal Arcs
  - Thermal Arcs

**Background Ionization**

**Current I, Amps**

$V_B$
Sputter deposition setup

Steps of the sputtering process

• Plasma provides ions
• Ions accelerated in electric field between target (cathode) and substrate (anode)
• Sputtering of target
• Transport of sputtered material
• Adsorption to substrate
• Surface diffusion
• Nucleation and film formation
Ion interaction with target

Increasing ion energy

E<10eV Adsorption, bouncing off surface, or surface damage
10eV-5keV Sputtering
E > 5keV Ion implantation

At sputtering energies

- Nuclear stopping is effective
- Interaction with top layers

Sputtered atoms typically have 10-50eV of kinetic energy

- Two orders of magnitude larger than for evaporation
- This leads to better surface mobility when the atoms reach the substrate

Elastic collision: Conservation of momentum and kinetic energy

- A qualitative view of sputtering can be achieved by considering an elastic model
- But for a thorough analysis one need to consider the coupled effect of bond breaking and physical displacement
Sputtering parameters

• Deposition rate (Å/sec, micron/min)
• Substrate temperature
• Gas pressure/plasma type (DC, RF, microwave, hot filament)
• Target/substrate geometry, relative motion (uniformity)
• Distance between target and substrate
Sputter yield

Depend on

- Ion and target atomic mass
- Ion energy
- Target crystallinity
- Angle of incidence

\[ S = \frac{\text{number of sputtered atoms}}{\text{number of incident ions}} \]

Figure 12.15 Typical angular dependence of the sputter yield for several different materials. The sputter profiles follow a cosine distribution (after Wehner, reprinted by permission, AIP).

Figure 12.13 Sputter yield as a function of ion energy for normal incidence argon ions for a variety of materials (after Anderson and Bay, reprinted by permission).
Stoichiometry and step coverage

Deposited stoichiometry depend on differences in thermalisation in the plasma
• Multiple targets
• Different areas on target
• Use target composition to yield the wanted film composition

Base pressure is also important for the film quality, as contamination by N and O can affect the reflectivity of the film.

Step coverage improvement by:
• Heating
  • Diffusion
• Biasing
  • Resputtering
Advantages of sputter deposition

• Low substrate temperature

• High melting point materials can be deposited

• Good adhesion

• Good step coverage compared to evaporation

• Less radiation damage than e-beam evaporation

• Well suited for alloys and compounds

• Versatility and scalability
Application examples of sputtering

• Developed in last 30yrs into a sophisticated coating tool

• Optical-interference filters and protective coatings for lenses, mirrors, transparent conductive coatings (ITO), for displays, heat filters for architectural glass

• Mechanical-hard coatings for tools, low friction coatings for bearing surfaces, anti-corrosion coatings in aircraft industry

• Electronics - especially semiconducting industry, metallisation, barrier layers, display circuitry, discrete components
Types of sputtering systems

• **Diode** (1960s, slow, rather high pressure [~0.1mb], secondary electrons at substrate, tendency to arc, conducting targets only)

• **R.F.** (60s,70s, good for insulators, slow, lower pressure than diode, [~0.005 mb], secondary electrons at substrate)

• **Magnetron (DC and RF)** (late 70s, 80s) (the modern system, fast [minimising contamination], low pressure [minimal pump throttling needed hence improved pumping of contaminants], no secondaries to heat substrate)

• **Ion beam** (for ultra-clean work, research, slow,)

• **Hybrids** (all types of combination system, may include evaporation, microwave sources etc.)
In a DC diode sputtering system, Argon is ionized by a strong potential difference, and these ions are accelerated to a target. After impact, target atoms are released and travel to the substrate, where they form layers of atoms in the thin-film.
Problems with DC sputtering

• Relatively high pressure overloads pumps, means contamination, lack of control over process.

• Bombardment of substrate by energetic neutrals and -ve ions (contamination)

• Bombardment of substrate by energetic secondary electrons (heating)

• Cannot be used with insulating targets; arcing by surface charging

• Low deposition rate (increases contamination)
Alternatives to DC Sputtering

• Reduce working pressure (increase plasma density for a given working pressure), by additional excitation:
  
  1. R.F. (13.56MHz)
  
  2. External magnetic coils.
  
  3. Use an ion beam system in UHV (very slow)
  
  4. Magnetron sputtering - has become the industry norm.
Magnetron sputtering

- Here magnets are used to increase the percentage of electrons that take part in ionization events, increase probability of electrons striking Ar, increase electron path length, so the ionization efficiency is increased significantly.

- Another reasons to use magnets:
  - Lower voltage needed to strike plasma.
  - Controls uniformity.
  - Reduce wafer heating from electron bombardment.
  - Increased deposition rate
  - Good control over reactive sputtering

In a non-magnetron sputtering system, the plasma is not confined, and electrons and Argon ions propagate through space, sometimes colliding with the substrate.

In a magnetron sputtering system, the plasma is confined to an area where the magnetic field is strong. The nearness of the plasma to the target causes faster deposition rates, greater Argon ion replenishment, and less substrate damage from stray particles.
Schematic representation of the plasma confinement observed in conventional and unbalanced magnetrons.
Things affect film structure

- Things that control grain structure are:
  - Substrate
  - Base pressure (or contamination level)
  - Deposition temperature
  - Deposition rate
  - Later processing temperature
  - Process pressure (#collisions)

Sputtering – thin film properties affected

- Stress
- Crystallinity/amorphousness
- Gas and other impurity incorporation
- Density and structure
- Stoichiometry or composition
- Effect of all above on optical, electrical, magnetic or mechanical properties.
Sputtering of compounds

• Compounds of two or more components are possible

Methods

• Several targets (co-sputtering)

• Compound or alloy target

  (Note: components sputter at different rates, but an equilibrium will be established after a certain time which results in composition of original target material being deposited as a thin film. The exception is when component is released as a gas ($O_2$, $N_2$), and hence depleted from depositing film.)

• Multi-component target (discrete pieces of second material)
Reactive sputtering

• The main problem is **control**:

• The critical reaction occurs at the target surface

• A mixture of argon and reactive gas (O$_2$, N$_2$) is used.

• Too much reactive gas, sputter-yield falls, gas build-up uncontrollably and deposited layer is **gas-rich**.

• Too little reactive gas, sputter-yield increases uncontrollably and layer is **metal-rich**
DaON-1000S sputtering system

R&D Sputter system
DaON-1000S is R&D equipment to research characteristics of the thin film and develop devices to be used co-sputtering system for making in-situ multilayer thin films.

Applications

1. Magnetic Data storage
   - CoRt, FePt, CoCrPt, etc.
2. Electronics & Semiconductor
   - Ag, Al, Au, Cr, Ni, Pd, etc.
3. Display
   - LCD(TFT & color filter)
   - PDP(PDP-filter)
   - OLED, Touch Panel, Electric Paper
4. Glass
   - Architectural Glass
   - Automotive glass
   - Anti-reflective and Antistatic coatings
5. Photovoltaic
   - CIGS, Si based thin films, CdTe wafer based cells

Fig. DaON-1000S
Major Specification

1. Process Chamber
   - Base Pressure: 5 x 10^{-6} Torr
   - Material: SUS304
   - Type: "D" Shape Chamber
   - Dimension (mm): W450 x D450 x H450
     Chamber wall water cooling
   - Top & bottom Port: ISO250
   - Pumping Port: ISO200
   - View Port: ISO80
   - Extra Port: 2.75" CF

2. Pumping Unit
   - Rotary Pump: Woosung vacuum/ MVP36 3Ph 60Hz(600lpm)
   - Turbo Molecular Pump: OSAKA TG11000FBWB, Port: ISO200

3. Heater Module
   - Position: Top of Process Chamber
   - Lamp: 110V, 210mm x 3ea
   - Temperature Control: PID with thermocouple/Max 650°C heating

4. Substrate Module
   - Sample Size: 2" wafer
   - Rotation: 0~20 rpm (DC gear motor)

5. RF Magnetron Sputter
   - 2" three magnetron sputter cathode mount

6. Gas Supply Unit
   - Gas: Ar : 100sccm, N_{2} : 100sccm, O_{2} : 100sccm
   - Valve: 1/4" Diaphragm Valve
   - Throttle V/V: CDG linked position control

7. Pressure Measurement
   - Low vacuum: APG100-XM (Edward)
   - High vacuum: AIM-S-NW25 (Edward)
   - Absolute gauge: BARATRON 626B(MKS, 1 Torr)

8. System Frame
   - Size (mm): W1,300 x D800 x H1,800
Safety measurements

1. Electric shock
   1) Power breaker off, before maintenance
   2) Do not touch power connector
   3) Do not step on cable

2. Burn scald
   1) Rotary pump is hot
   2) TMP surface is hot
   3) Substrate is hot
1. Sputter machine check

(1) Check list

1) Account for check list

Before sample loading, every times.
Feel sound, temperature.

2) Utility

- Electricity: 220 V, A
- PCW (Process cooling water):
- CDA (Compressed dry air):

3) Gun

- Target state
- Gun insulation
- Shield particle
- Gun shutter moving

4) Rotary vane pump

- Volume of oil
- Color of oil

5) Turbo molecular pump

- Water leak
- Sound of moving

6) Process gas

- Residual pressure
- Supply pressure

7) Door O-ring

- Stabbed
- Particle
Explanation of Pump/Valve operating

Sputter chamber

Roughing valve

Gate valve

TMP

Fore line valve

Leak valve

Rotary vane pump

N₂ MFC

Ar MFC

O₂ MFC

Substrate Rotation

Sputter gun1 shutter

Sputter gun2 shutter

Sputter gun3 shutter
Sputter gun target change

1. Target shield bolt remove

2. Target clamp bolt remove

3. Target install / remove

Gun body
[ 3D Modeling ]

1. Front View
2. Back side View

[ Inside View – Chamber Module ]
3-Magnetron cathode with shutter

- Target Size: 2"
- Pneumatic shutter
- Co-position
- Power: DC 1Kw 2set
- RF 300W 1 set

2" Magnetron cathode

Shutter

Adjustable bracket
- Angle adjustment by bolt

Shutter F/T

Power Connection
[ CDA Module ]

[ Utility back Side View ]

Main Power Cable

Gas Supply - ¼" Lok Fitting

Rotary Pump Oil Level Window

PCW In/Out 12mm tube

Exhaust - KF25

CDA Supply 8mm tube

[ Gas Line Module ]

[ PCW & Rotary Pump ]
a. Chiller (PCW)
b. Compressor (CDA)
c. Transformer

(1) Turn On
(2) Reset
3) Chamber vent
4) Substrate shutter
5) Sputter gun-1 shutter
6) Sputter gun-2 shutter
7) Sputter gun-3 shutter
8) Rotary Pump (RP)
9) Rotary Valve (RV)
10) Fore valve (FV)
11)........
12) Gate Valve
13) Capacitive diaphragm gauge
Vacuum gauge controller

(11) TMP controller ON/OFF
(14) Throttle valve controller

Working pressure can be adjusted according to the requirement using SP1-SP5 for five different ranges.

(15) Temperature controller

Substrate temperature can be adjusted upto 500°C.
(16) Rotation controller

Substrate rotation can be adjusted according to the requirement.

Mass flow controller

Gas (argon, nitrogen, oxygen) can be controlled using MFC.
DC power supplies for Sputter guns 2 and 3.

RF power supplies for Sputter gun 1.
Remarks

• High quality thin films
• Uniform and phase pure structure
• No contamination due to high vacuum
• Layered structures
• Compound thin films
• Oxides and nitrides formation using reactive sputtering
• Etching of substrate and target