

# Intlvac Nanochrome I Sputter System (intlvac\_sputter)

## 1. Intlvac\_Sputter Specifications

The Intlvac Nanochrome I sputter system is configured for DC, AC (40 kHz), and RF (13.56 MHz) magnetron sputtering. The system has in-situ quartz lamp heating up to 200C, ion beam assisted deposition (IBAD), pre-sputter etch, substrate DC bias and is plumbed for reactive oxide and nitride depositions. The three magnetrons require 3" circular targets and are indirectly cooled. The two front two magnetrons are multipurpose. They may be used as individually in DC or dual mode AC. The back magnetron is dedicated for RF deposition. Dual AC mode is recommended for reactive depositions, as it has a much higher deposition rate than a single RF or DC magnetron. Dual AC is also useful for increasing the deposition rates for metallic films.

Control of the system is through an industrial PLC with a LabView interface for fully automated depositions. Four, 4" Substrates are loaded on to a ten inch carrier assembly that is fixed to a rotating hub. The system is plumbed with 3 process gas lines, Argon, Oxygen and Nitrogen, each line has a dedicated mass flow controller. The gas lines are all 10 RA electropolished UHP piping and gas line and are fitted with 9Log, getter purifiers and particulate filters. The system vent is fitted with a gas diffuser to prevent turbulence during venting.

## 2. Pre-Sputter Etch

The system is equipped with a low energy ion Mark I Ion Source. The Mark I source is a Gridless End Hall Ion Source used for substrate precleaning and ion beam assist deposition (IBAD). The ion source is mounted on scaffold assembly which allows angular and linear adjustment between the source and substrate. Argon to the ion source is supplied through a calibrated mass flow controller. Operation of the ion source and the MFC is through the system controller. Detailed process characterization has not been completed, but etch rates on blanket SiO<sub>2</sub> of greater than 90 Ang/min with a non-uniformity of approximately 10% have been demonstrated.

## 3. Aluminum

Aluminum films were deposited using the dual AC configuration. The use of dual AC allows for deposition rates greater than 1 um/min.

### 3.1 Aluminum Deposition Rate

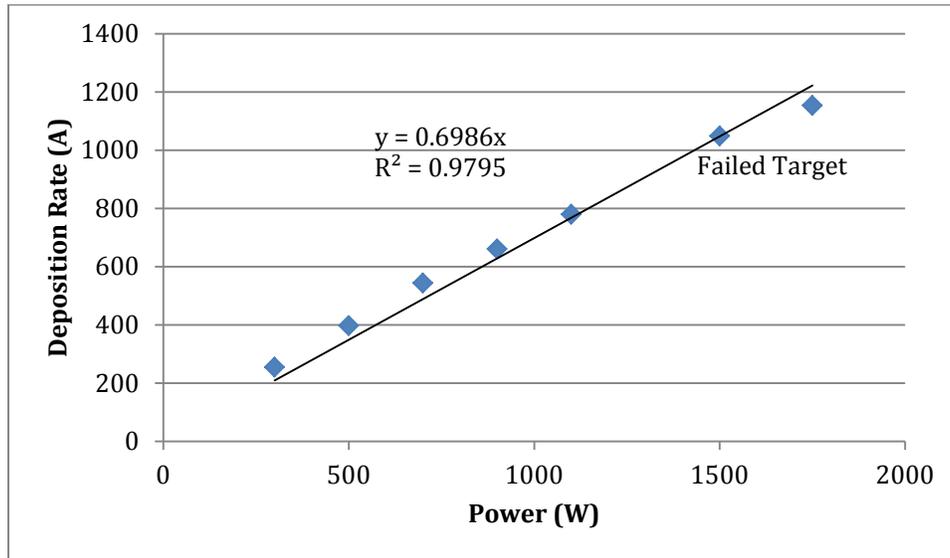
To measure the Al deposition rate, photoresist stripes were placed at 5 locations on a wafer (center, top, left, bottom, and right). The Al films were deposited and lifted off from the resist stripes using IPA. This results in a trench in the Al film. The resulting step heights were measured using the Tencor P2 profilometer. We repeated the procedure at deposition powers from 300-1750 W. All depositions were performed in dual AC mode for 5 min at 6 mT (courtesy Ed Myers). The deposition rates are summarized in the table below along with sheet resistance and reflectance measurements that will be discussed later.

	300 W	500 W	700 W	900 W	1100 W	1500 W*	1750 W
Deposition rate (A/min)	255	398	544	661	780	1,049*	1,154
Sheet resistance ( $\Omega$ /sq)	3.80E-1	1.98E-1	1.36E-1	1.05E-1	8.63E-2	6.79E-2*	5.82E-2
Reflectance	1.00	0.991	0.983	0.965	0.948	0.765*	0.874

\*One target failed by coming loose from the keeper.

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The plot below shows deposition rate versus power. As expected, the deposition rate is linearly dependent on power.



### 3.2 Uniformity

The table below provides the five step height measurements taken on each wafer. This data shows that the within-wafer thickness variation is ~10%. For all depositions, the wafer flat was aligned closest to the center of rotation and the rotation speed was 50 RPM. Note that the films are systematically thinner at the top of the wafer (near the outer edge of the wafer holder). If the top point is not included, the variation amongst the other points is < 5%.

AlphaStep	300 W	500 W	700 W	900 W	1100 W	1500 W*	1750 W
Center	1,234	2,188	2,821	3,435	4,125	5,509*	5,926
Top	1,117	1,547	2,354	2,764	3,376	4,473*	4,796
Left	1,297	2,066	2,768	3,477	3,950	5,574*	6,187
Bottom	1,367	2,007	2,885	3,490	4,054	5,646*	5,961
Right	1,350	2,154	2,775	3,362	3,986	5,027*	5,984
Mean	1,273	1,992	2,721	3,306	3,898	5,246*	5,771
Std Dev (%)	7.97	13.0	7.73	9.28	7.68	9.45*	9.61
Std Dev, no Top (%)	4.57	3.92	1.92	1.68	1.92	5.15*	1.95
Sheet Resistance							
Uniformity (%)	10.1^	9.7^	12.5	12.0	11.36	11.76*	11.5/9.1^

\*One target failed by coming loose from the keeper.

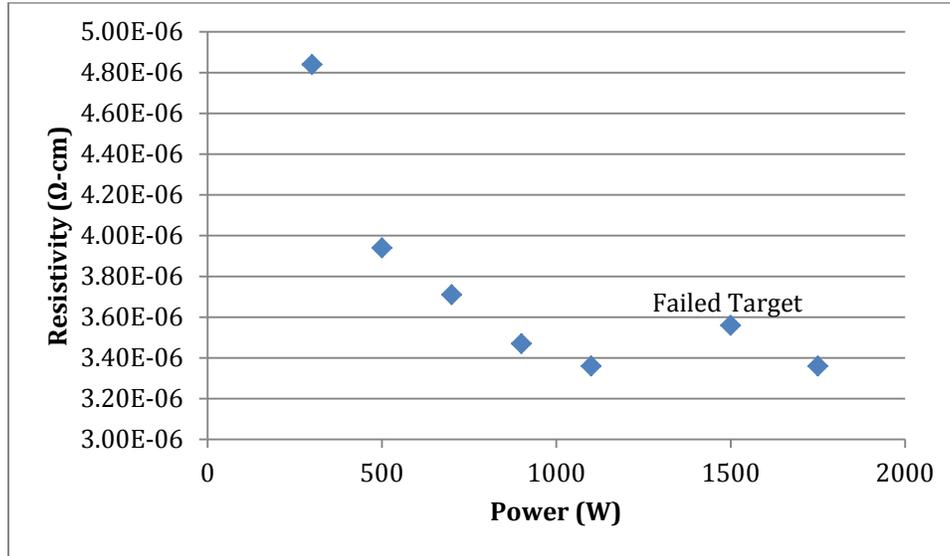
^Uniformity calculated from 49 point measurements, others are from 5 pt. measurements.

### 3.3 Resistivity

In addition to thickness, we also measured the sheet resistance of the Al films. The measurements were again taken at 5 locations on the wafer using the Prometrix four-point probe. The mean sheet resistance at each power level is provided in an earlier table. Using this data and

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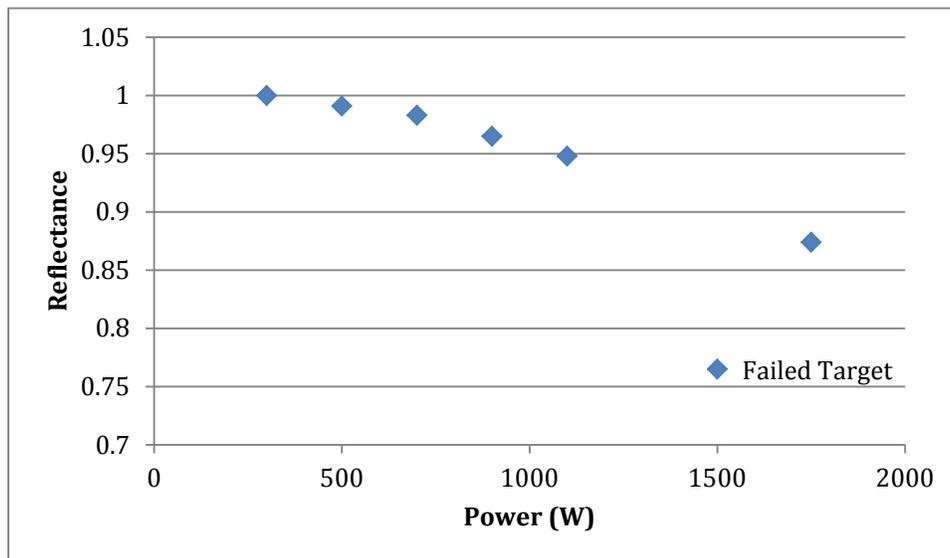
the mean film thickness, we can calculate resistivity, which is plotted below as a function of power.



The published bulk resistivity of Al is 2.8E-6 (Ω-cm), which we begin to approach at the high powers which are also thicker films. At low power, two factors are likely to cause an increase in resistivity. First, because the films are thinner, there is increased electron scattering at the interfaces. Second, during the deposition, the wafer temperature is lower, resulting in smaller grain structure and enhanced scattering at grain boundaries.

### 3.4 Reflectance

As the deposition power for Al was increased, the specular surface of the Al film was became darker in color. The chart below shows the normalized reflectance compared to the high specular 300W dual AC Al deposition. The change in specular appearance of the film was associated found to be related to preferred grain growth roughening.



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### 3.5 Wafer Temperature

The Intlvac sputter system does not have active wafer cooling such as backside chilled water. Instead, thermal energy is dissipated from the wafers passively by conduction through the wafer holder and by radiation. However, the contact area between the wafers and the holder is small (only the edges of the wafer touch the holder while the front and back surfaces are bounded by vacuum), limiting the effectiveness of conduction.

In order to investigate the wafer temperature during deposition, we attached Omega temperature dots to the back of a wafer and encapsulated them in Kapton tape. The dots had a temperature range of 79°C to 149°C. We deposited pure Al in dual AC mode in the Intlvac tool and observed the maximum wafer temperature recorded by the dots. mAs a basis for comparison, a similar deposition was performed in the Gryphon tool. Data from the Gryphon are courtesy of Jim Kruger. The results are presented in the table below.

	intlvac_sputter	Gryphon
Pre-sputter etch	30 seconds (120 V, 0.5 A)	90 seconds (600 V, 0.25 A)
Deposition mode	Dual AC magnetron	DC magnetron
Power	1.1 kW	7.5 kW
Time	12.8 min	5 min
Nominal thickness	1 $\mu\text{m}$	0.5 $\mu\text{m}$
Wafer temperature	135°C-149°C	93°C-107°C

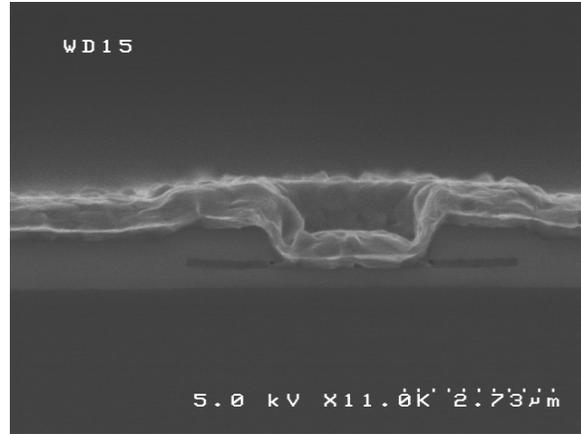
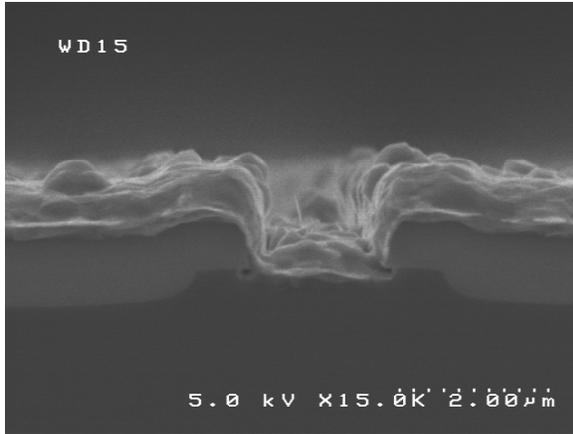
We see that the wafer temperature in intlvac\_sputter is at least 28°C higher than it is in Gryphon, which supports the hypothesis that the hazy Al films are caused by large grain structure.

### 3.6 Step Coverage

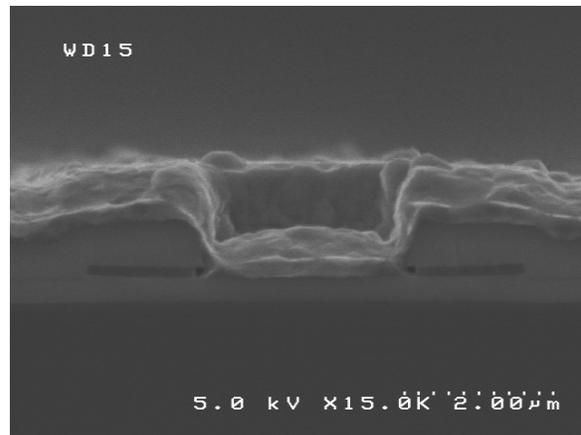
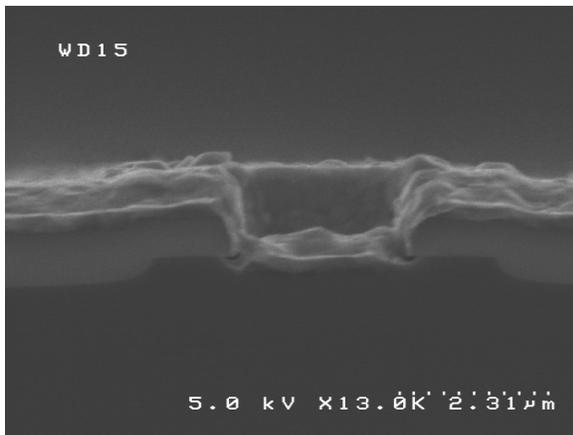
Sputtering generally results in better step coverage than e-beam evaporation. We verified the step coverage in the Intlvac tool using a wafer from the EE410 class. We stripped the top level Al+1% Si metal which had been deposited in Gryphon with a wet etch in Al-11 (wbgeneral) followed by a “freckle” etch in CF<sub>4</sub>+O<sub>2</sub> plasma (drytek2). Next, we deposited a new Al layer in the intlvac\_sputter, filling the exposed 1  $\mu\text{m}$  deep contacts and vias. We performed the 10 min deposition at 1500 W and 6 mT in dual AC mode, which we expected would yield a 1  $\mu\text{m}$  thick film. We cleaved through contact and via chains at the center and edge of the wafer and observed the sidewalls under SEM. Representative images of contacts (left) and vias (right) are provided below.

Center

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Edge



The images show that although the film thickness is only ~600 nm, the sidewalls of the 1 μm deep vias are covered.