How to Make Manufacturing of LEDs Truly GREEN

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Overview

- Progression in Lighting Sources
- Typical HBLED Device Structure
- Current HBLED Manufacturing Process
- Precursors – TMG & Ammonia
- Ammonia in LED Manufacturing
- Issues: Ammonia Production & Purification
- Atomic Precision's Solutions
- Novel Reactor
- Alternative to Ammonia

Lighting Sources

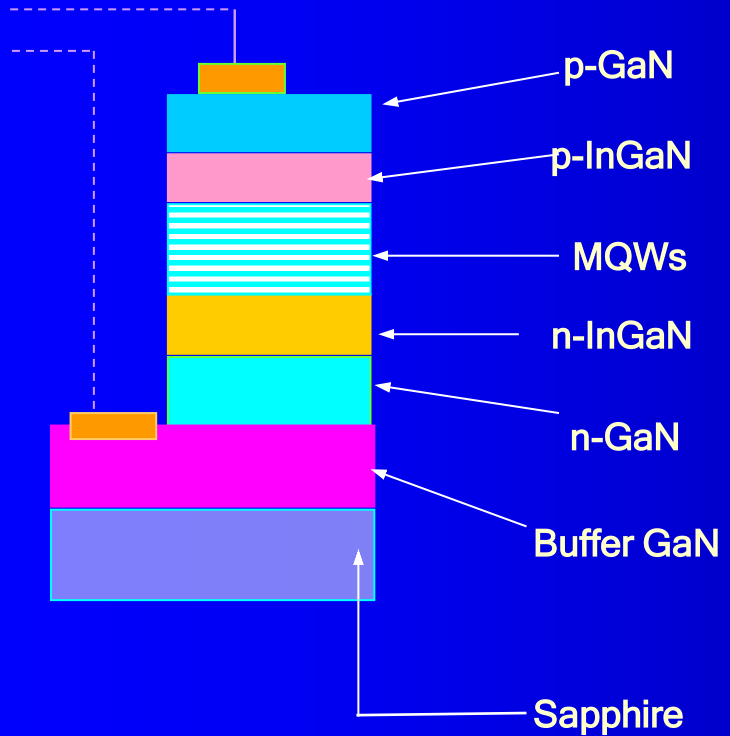
5W, 20Yrs, $15

15W, 3Yrs, $3.0

60W, 1.5 Yrs, $1.0

HBLEDs - Current Applications

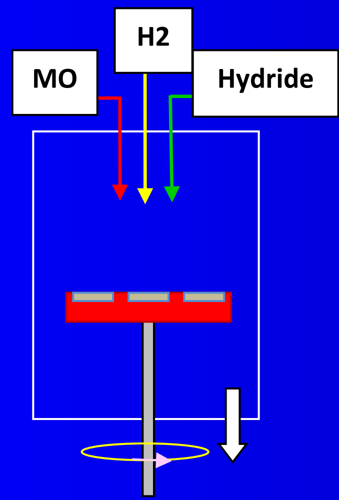
HBLED Device Structure



Device Layers

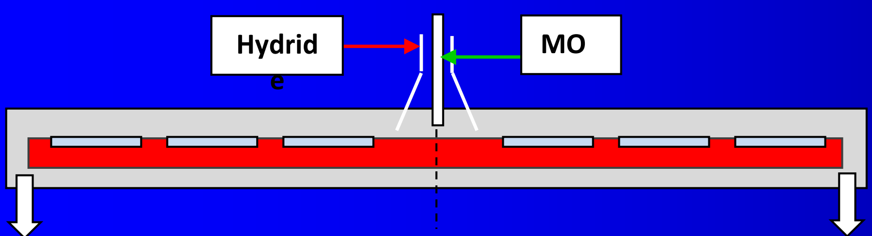
- Buffer GaN (4 to 6 μ)
- n-GaN & p-GaN (2 μ)
- InGaN: In & Ga % varies
- MQW: Quantum Wells
- Total stack: 8 – 10 μ

Current MOCVD Tool Configurations



Vendor - A

- Turbo-Disk; MO + Hydride
- 3-inch x 24 Wafer Capacity



Vendor - B

- Planetary Motion of Wafer
- 3-inch 24 Wafers
- Compact Design

MOCVD: Current Thin Film Process

$$Ga(CH_3)_3 + NH_3 \rightarrow GaN + 3\ CH_4$$

- ✓ Process Temp. = 900 – 1,000 °C
- ✓ Chamber Pressure = x 100 mT
- ✓ Deposition Rate ~ 2 micron/h.
- ✓ Rigorous "O" Exclusion Required
- ✓ H_2 Added to Gas Mixture
- ✓ $GaN + H_2 \leftrightarrow Ga + NH_3$
- ✓ Ammonia added to "Reverse" GaN decomposition
- ✓ Typical Ammonia Flow Rate ~ 50 slpm
- ✓ Typical "Batch" Process Time ~ 5 h.

Volume of Ammonia Required

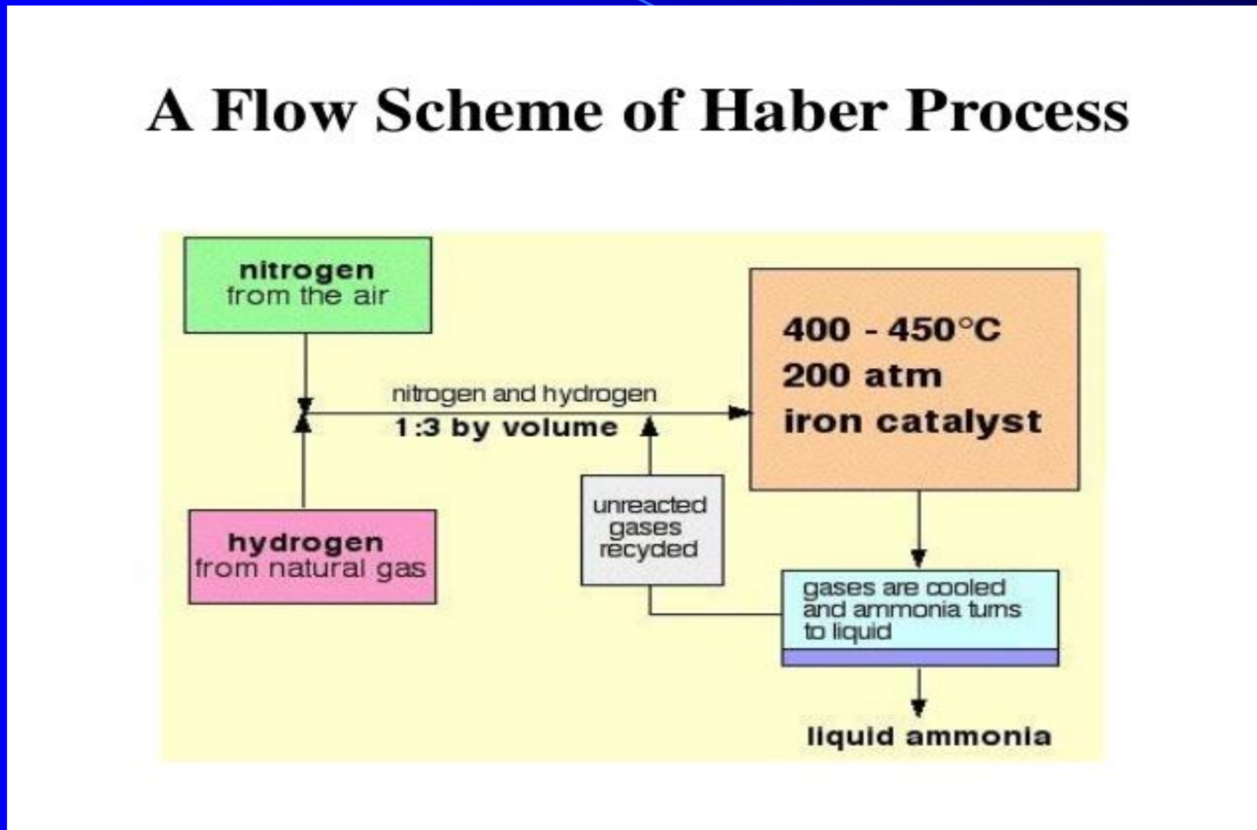
= 0.6 x 50 slpm x 60 min/h x 24 h/day x 365 days/year

= 15,768,000 Liters/year/Tool

@ 60% Tool Uptime!

Hundreds of Tools Worldwide!

Industrial Ammonia Production



Energy consumed in N_2 separation and H_2 generation

HBLED Mfg: Required Ammonia Purity

Spec Gas Supplier	Total Purity %	H2O ppb	O2 ppb	CO ppb	CO2 ppb	Total ppb oxygen compounds
White Grade	99.99999	1	10	10	50	71
B	99.99999	60	30	30	50	150
C	99.99997	5	50	30	50	135
D	99.99995	100	50	50	100	300

Ref. : R. W. Ford, Gases & Instrumentation, pp. 26, May/June 2013.

Ammonia Supply in Manufacturing

Ref. : R. W. Ford, Gases & Instrumentation, pp. 26, May/June 2013.

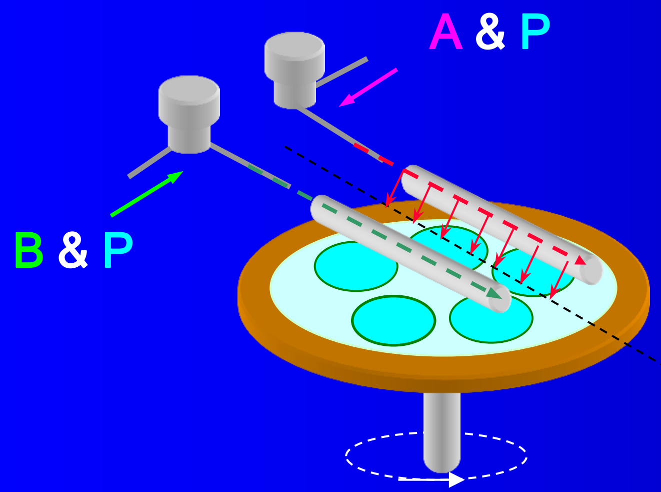
Issues in Ammonia Supply

- Ammonia is a refrigerant
- During transport cools on expansion
- Couplings, elastomer seals freeze → icing
- Couplings, seals loosen when frozen
- Strong possibility for Re-entry of all "O"s
- Must be "Re-purified" before entry into MOCVD
- Additional cost and energy expended

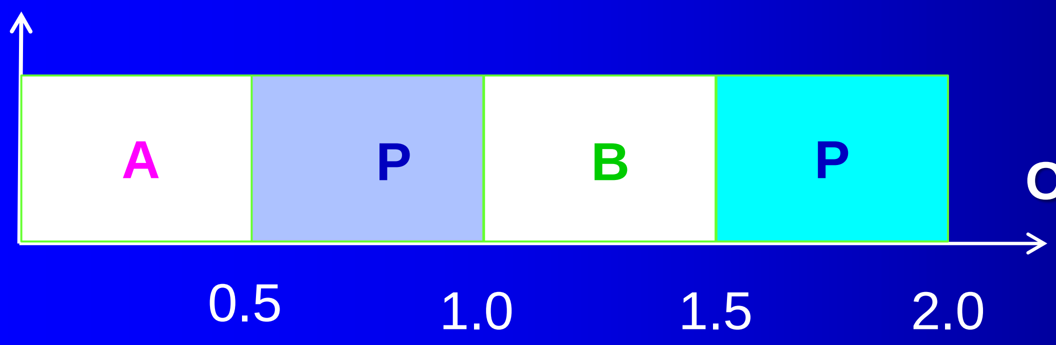
Solutions by Atomic Precision

1. Novel High-speed Reactor
2. Ammonia **Free** chemistry
3. Substitute for $Ga(CH_3)_3$

1. Novel High-speed Reactor

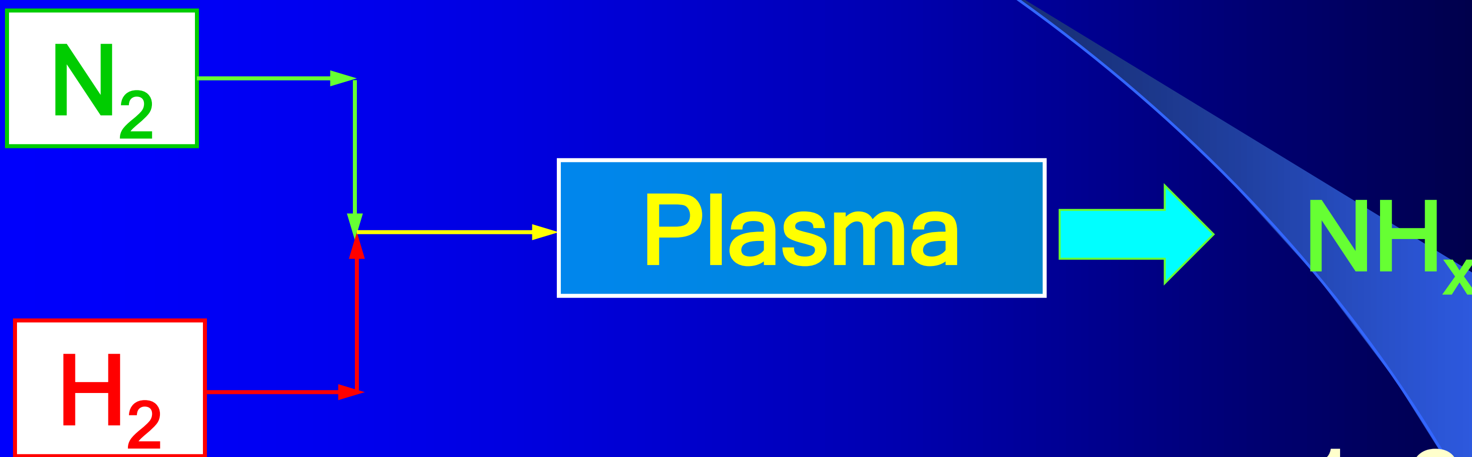


- ✓ Linear Injectors w/ Apertures
- ✓ Rapid Uniform Coverage
- ✓ ALD & CVD in One Chamber
- ✓ Thin & Thick Films
- ✓ Chemistry Flexibility



Prasad N. Gadgil, US Patent No. 6,812,157

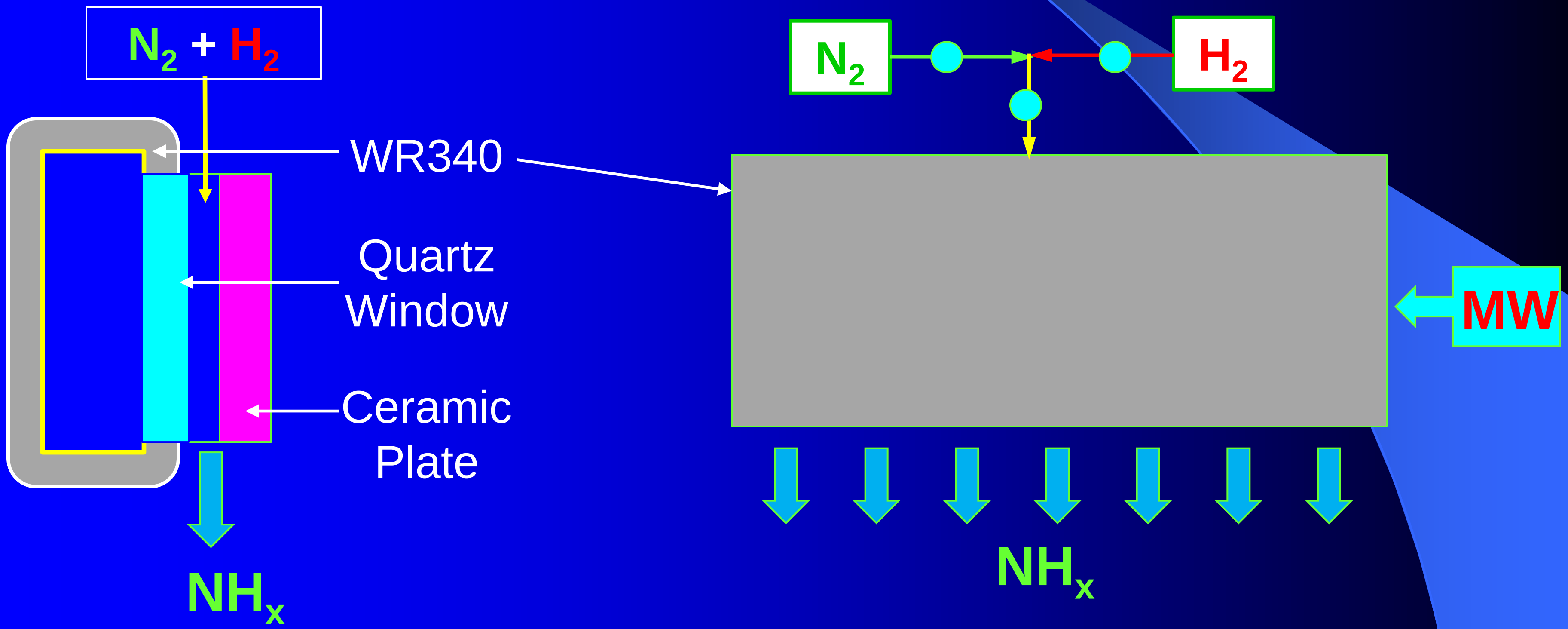
2. Ammonia FREE Chemistry



x = 1, 2, 3

Ammonia FREE Chemistry

Low Volume Linear MW Plasma Applicator

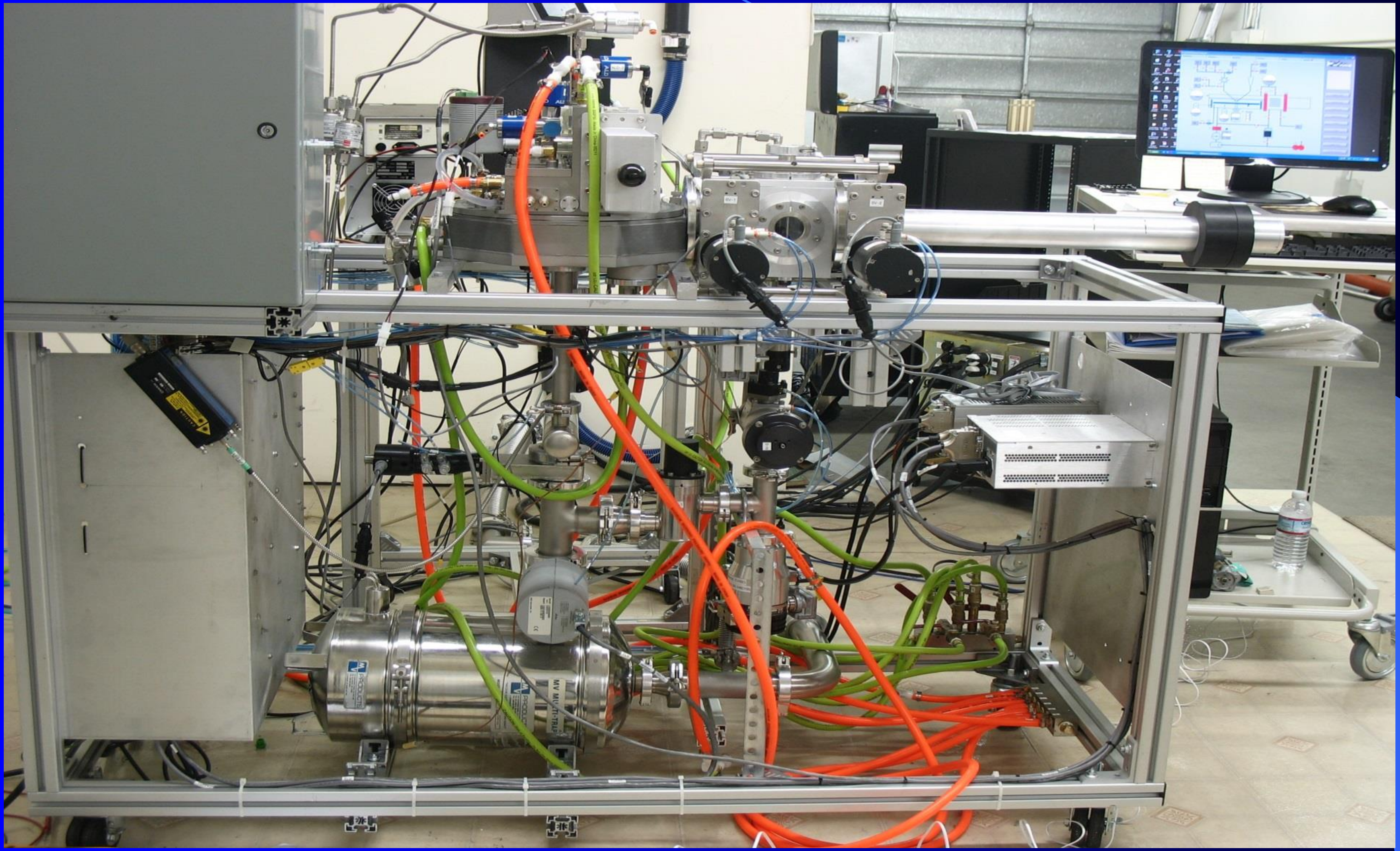


Replace $Ga(CH_3)_3$ by $GaCl_3$

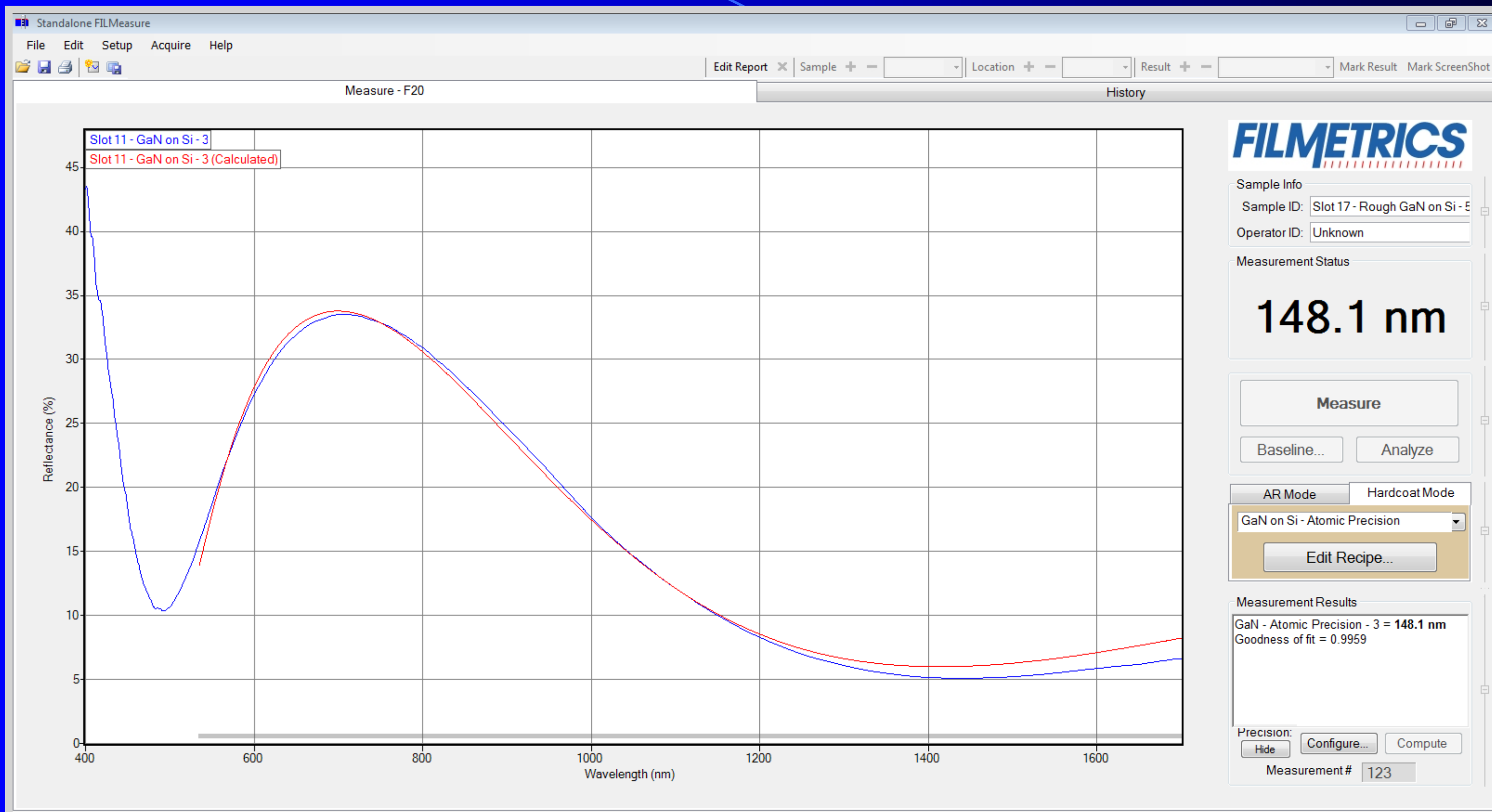
	TMG	**$GaCl_3$**
State	Liquid	Solid
m. p. (°C)	- 15.8	78
b. p. (°C)	55.7	201.3
Cost ($/g)	20*	< 1.0 §

- * and §: Estimated bulk cost
- $GaCl_3$ can be molten and added via a linear injector

C&F GaN System – Atomic Precision



GaN: n&k Analysis



N_2 = 25 sccm, H_2 = 75 sccm, 500 °C, 700 mT, 500 W MW

Advantage – Atomic Precision

HBLED Production Technology - Factors	(MOCVD)	Atomic Precision
Chemical Cost (per g)	10	1x
Chemical Utilization Efficiency	~ 25 %	> 80%
Film Deposition Rate	~ 2 μ/h	~20 μ/h
Undesirable "C" in Film	Yes	No
Process Automation Potential	Marginal	Full
Product Yield	< 60%	N/A
Product Cost	10x	1x

† : Estimated.

Summary

- ✓ Enabling Equipment & Process Technology
- ✓ HBLED Cost Reduction by approx. 90%
- ✓ Environmentally Clean and GREEN Process

Thank You!