Repair, Reconfiguration and Reconstruction of Tools by Direct Metal Deposition

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Auburn Hills, MI-48326

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OUTLINE

- POM GROUP, INC.
- NSF Industry-University Co-Operative Research Center
- Direct Metal Deposition(DMD)
- DMD Application in Tools and Dies
- DMD and Environment
- DMD future application
- SUMMARY
POM GROUP INC. - WHO ARE WE?

- POM is a minority owned product development service bureau & OEM machine supplier in Auburn Hills, Michigan for DMD technology whose purpose is to:
  - **Commercialize** new metal fabrication technology (Direct Metal Deposition-DMD)
  - **Provide engineering product development services** to demonstrate the benefits of DMD technology in speeding new products to market.
  - **Supply production DMD equipment** and ancillary peripherals associated with tooling fabrication, reconfiguration & restoration

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Awards & Accomplishments

- **ASME Thomas Edison** Award for JM FOR DMD Patent-2010
- **Supplier of the Year – 2002** (MMBDC)

National Minority Supplier Development Council, Inc.

2002 National Supplier of the Year
POM Core competence

- **Closed loop** near net shape deposition systems and services
- R&D on DMD process and systems and development of IP
- Design and fabrication of sophisticated and Custom DMD systems

University I/UCRC Mission
Center For Laser Aided Intelligent Manufacturing

Goal
• To develop a fundamental understanding of laser-aided intelligent manufacturing to reduce lead-time from concept to product.
• To transfer this technology to industry.
• To educate both students and industrial personnel in the basic cross-disciplinary science and technology.

Approach
• To develop a fundamental understanding of laser-aided intelligent manufacturing to reduce lead-time from concept to product.
• To transfer this technology to industry.
• To educate both students and industrial personnel in the basic cross-disciplinary science and technology.

Modeling

Measurements
- Reflective Topography
- Electron Density Distribution by Absorption Spectroscopy

Applications
- Direct Materials Deposition

Industries Sponsors:
- PLM Consortium: 19 Major Industries
  - Aetna, General Motors, Ford

Research
- Aluminum Welding
- Steel Welding
- Drilling

What Is DMD?
- LASERS
- CAD
- CAM
- SENSORS
- Powder Metallurgy

DMD: “Blending” of Five Common Technologies

Contact:
Debbie Hemmeter (Hemmeter@umich.edu)
Overview

DMD Process Overview

1. Direct Metal Deposition
   • High power laser builds parts layer-by-layer out of gas atomized metal powder

2. DMD Characteristics
   • 0.005” dimensional accuracy
   • Fully dense metal
   • “Controllable” microstructure
   • Heterogeneous material fabrication capability
   • Control over internal geometry

Blending of 5 common methodologies:
   • Laser
   • CAD
   • CAM
   • Sensors
   • Power Metallurgy

Omni directional concentric laser-powder-gas nozzle
Closed-Loop Process

- Improves dimensional accuracy
- No need for intermediary machining of parts when deposit builds irregularly
- Near net shape within fraction of millimeter is possible
- Resulting in significantly reduced post DMD finishing and reduced cost
- Better thermal control and thus better microstructure control
- Better microstructure leading to better mechanical properties
- Significantly reduced distortion and thus post process complication and cost

Left: DMD with feedback control
Right: DMD without feedback control

Moving Optics

- Part mass does not affect the usable work envelop (Velocity, acceleration etc)
- Part handling concerns reduced
- Angular deposition without moving part

Note Complex angles of deposition
How does DMD Machine Looks Like?

DMD Process Overview

Why moving optics?

• Part mass does not the usable work envelop (Velocity, acceleration etc)

• Part handling concerns reduced

• Angular deposition without moving part

10 Tons

Note Complex angles of deposition

POM Products
DMDCAM

Features

- First comprehensive 6 axis CAM software package for Additive Manufacturing
- Integrated Direct Metal Deposition (DMD) technology database
- Contour, Surface and Solid deposition paths in 3D
- Maintains constant Stepover distance along the deposition path.
- Multi-layer deposition paths in a single operation
- Simulation and collision detection modules for “Ready to Use” deposition path
- Deposition paths for most of the leading controllers (Siemens, Fanuc, Delta-Tau)

Energy, Environment, Economy

DMD Process Overview

- Will save energy
- Will provide designed functionality
- Will reduce lead time & Economy friendly
- Environmentally Benign
**Process steps**

1. **CAD Model**
2. **Import (IGES)**
3. **Slicing**
4. **Toolpath Generation**
5. **CNC G-code**
6. **Uploading**
7. **Substrate preparation**
8. **Remote engineering**
   - **Customer data**
9. **Post operation**
   - **Machining EDM**

**Aerospace Industry: Lattice Structures**

*NASA mirror*

**Advantages:**
- Automated process / Precision control
- Near net shape / list post-machining needed
- Material saving *(expensive super alloys)*
- Cost saving
- Energy saving
- Shorter lead time
Aerospace Industry: Turbine blade/vane/seal repair

Applications:
- Blade tip repair and build-up
- Seal replacement and build-up
- Knife edge seals
- Unlimited alloys
- Single Crystal and DS Alloy friendly

Advantages:
- Automated process / Precision control
- Near Net Shape
- Thin Layers/Less Weld Clean-up
- Low Heat Input/less part distortion
- Small heat effected zone/low dilution
- Simple Low Cost Tooling/Fixturing
- Shorter remanufacturing time
- Cost saving

Trimming Industry: Trim Insert for Aluminum Deck Lid

- **Technical challenge**
  - Severe wear on cutting edges due to material changes
  - Existing tooling large dimensions
  - Foreign competition
- **Laser (DMD) solution**
  - Tool steel CPM1V
  - Tool life before: 400 to 2,000 cycles
  - Tool life after: 10,000 pieces
  - 5X life improvement wear resistance
- **Economic impact**
  - Cost saving base material (right material at the right place)
  - Downtime reduced by 5X
  - Remanufacturing reduce 45% of cost new
  - Lead time reduce by 30% for new . More for used
  - Repeat remanufacturing for third life
Technology Enables Unique Applications in Tooling

1. Tool Reconfiguration
2. Tool Restoration
3. Thermal Management
4. Increased Tool Life
5. Additive Metal Changes

DMD APPLICATIONS

- Conformal cooling
  - Die casting
  - Plastic injection molding

- Hard facing / coating
  - Oil industry
    - Wood industry
    - Stamping
    - Trimming
    - Forging

- Remanufacturing
  - Turbine components
  - Large components with long lead time
  - Expensive components
  - Small engineering changes

- Special applications
  - Lattice structures
  - Valve seat cladding
CASE STUDIES for Tooling Reconfiguration

Case Study #1

Reconfigured Tooling
Case Study #1

Reconfigurable Tooling

2002 Prototype Tool

2003 Prototype Tool

Tool Cross Section

CNC Machine “surrogate” Tool

Deposit 0.090” DMD P20 tool steel surface

Remove 0.030” excess stock with CNC creating NuTool

Overlay new CAD

Offset surface 0.060”

Surrogate tool 1025 substrate
Case Study #1

Reconfigurable Tooling

BENEFITS

• Cost Avoidance (35%)
  - Elimination of "soft tooling" costs
  - Reconfiguration vs purchase of new tooling
  - Reduced material cost (LCS vs tool steel)

• Time Compression (65%)
  - Prototype parts in 5 weeks vs 14 weeks
  - Elimination of the timeline impact of "soft tooling"
Dependence on Scale

Direct Metal Deposition: Energy, Economy & Environment (E³)

- Will save energy
- Will provide designed functionality
- Will reduce lead time
- Economy friendly
- Environmentally Benign
Forging Industry : Connecting rod

- Technical challenge
- Severe wear and heat checking

- DMD solution
  Stellite 6 on S7
  - Tool life before: 5,000 cycles
  - Tool life after: 19,000 pieces
  - Tool Life Improvement: 4X

- Economic impact
  Cost saving by depositing only on critical area
  Remanufacturing : 45% of cost of new
  Lead time reduced by 30% of new
  Repeat remanufacturing for third life
POM Process

**Application:** Hot Forge - Upsetting

**Typical Tool Life:** 2,750 cycles

**Failure Mode:** Galling & Abrasive Wear

**DMD Application:** Bi-metallic: Cobalt-based deposition on H13 substrate

**Goal:** Increase useful die life

**Production Test Matrix & Results**

<table>
<thead>
<tr>
<th>Punch #</th>
<th>Substrate Material</th>
<th>DMD Material</th>
<th>Cycles</th>
<th>Life</th>
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<tbody>
<tr>
<td>1</td>
<td>H13</td>
<td>Stellite 6</td>
<td>8,000</td>
<td>3x</td>
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<tr>
<td>2</td>
<td>H13</td>
<td>Stellite 21</td>
<td>8,000</td>
<td>3x</td>
</tr>
<tr>
<td>3</td>
<td>Prestem B</td>
<td>H13</td>
<td>5,000</td>
<td>1.9x</td>
</tr>
<tr>
<td>4</td>
<td>Prestem B</td>
<td>Stellite 21</td>
<td>5,000</td>
<td>1.9x</td>
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</tbody>
</table>

**Project Status**

Part design was changed after production test.

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**Punch Head**

**BiMET - Bi-Metallic Tooling**

**Application:** Hot Forge - Upsetting

**Typical Tool Life:** 2,750 cycles

**Failure Mode:** Galling & Abrasive Wear

**DMD Application:** Cobalt-based deposition on H13 substrate

**Goal:** 5,500 -> 8,250 cycles (2x ->3x)

**Production Test Matrix & Results**

<table>
<thead>
<tr>
<th>Test Design</th>
<th>Cycles</th>
<th>Life</th>
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</thead>
<tbody>
<tr>
<td>Four (4) punch heads</td>
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<td>3x</td>
</tr>
<tr>
<td>2ea... Stellite 6 on H13</td>
<td>8,000</td>
<td>3x</td>
</tr>
<tr>
<td>2ea... Stellite 21 on Prestem B</td>
<td>5,000</td>
<td>1.9x</td>
</tr>
</tbody>
</table>

**Average Tool Life:** 5

**Average Improvement:** pending production test results

**Project Status**

Production test in-process. Waiting on production results.
APPLICATION: Hot Forge Stabilizer Eye Form Detail
TYPICAL TOOL LIFE: N/A
FAILURE MODE: Galling and abrasive wear
DMD APPLICATION: Cobalt-based alloy deposition on high strength steel substrate.
GOAL: 15,000 cycles

PRODUCTION TEST MATRIX & RESULTS

<table>
<thead>
<tr>
<th>Test Results (cycles)</th>
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<tbody>
<tr>
<td>Part</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>

PROJECT STATUS
POM proposal submitted for AMM review on 2/20. Proposal includes 8-piece lot sample quantity.

Sintered Metal forging:

- Technical challenge
- Galling & chamfer failure
- Life 10,000-15,000 cycles
- DMD solution
  - Stellite 6/706/21/31 DMD on wear areas
  - Clad thickness 0.030”
  - Economic impact
  - Life improvement 1-3 x with Stellite 6
- Reduced downtime
- Reduced part inventory

<table>
<thead>
<tr>
<th>Test Results (cycles)</th>
</tr>
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<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Stellite 6</td>
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<tr>
<td>Stellite 706</td>
</tr>
<tr>
<td>Stellite 21</td>
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<tr>
<td>Stellite 31</td>
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</table>
Forging Die: Wear resistant Coating

- Technical challenge
- Wearing and cracking at flash areas & die floor at arm ends
- Weld repair every 1300 hits

- DMD solution
- Cladding of the problem area with high wear resistant material
- Life improvement

- Economic impact
- Reduced downtime
- Reduced lead time
Forging Industry : Punch tips

- Technical challenge
- Severe wear

- DMD solution
  Stellite 6 on Steel

- Economic impact
  Reduction of down time
  Reduction of inventory

Crack Repair
Crack Repair: Stamping press dwell arm links

Technical Challenges:
- Repair of fatigue cracks
- Large part size and DMD volume

DMD solution:
- Big beam, high DMD deposition rate (~ 10 in³/hr)

Economic Impact:
- Cost saving (~80%)
- Shorter lead time (1 week against 3 months)

Total Energy consumption in USA exceeds 100QT BTU/yr
Traditional Manufacturing & The Environment

- Manufacturing consumes inherently limited resources and releases environmental toxins and CO₂, degrading the quality of the environment.
- Industrial sector is leading consumer of energy and most significant polluter of water.
- Manufacturing sector is leading producer of solid waste (~ 7B tonnes/year).
- Many processing steps to achieve products, implying high cost, time, and material/energy consumption.

Conformal Cooling – More Uniform Cooling Line Distance to Tool Face

- Conformal Cooling Line
- Conventional Drilled Cooling Line
- Part Temperature Variation due to Differences in Water Line Distances

Bishop, 1999
Cooling cycle comparison between straight line (conventional) cooling and conformal cooling

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Straight line cooling (s)</th>
<th>Conformal Cooling</th>
<th>% Savings</th>
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<tr>
<td>Semi-cylinder</td>
<td>6.6</td>
<td>4.1</td>
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<tr>
<td>U-plate</td>
<td>10.4</td>
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<tr>
<td>Hemi-sphere</td>
<td>14.0</td>
<td>5.4</td>
<td>61</td>
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<tr>
<td>Relay cover</td>
<td>10.1</td>
<td>4.5</td>
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Door Molding Tool: Part warpage

Warpage
HALF

Theoretical Modeling using Mold Flow

Energy & Cost Savings

<table>
<thead>
<tr>
<th></th>
<th>Vehicle Set</th>
<th>230 days</th>
<th>28 hours</th>
<th>48% per hour</th>
<th>55.4 per hour</th>
<th>utility $/h</th>
<th>Consumed</th>
<th>at 4600 hours</th>
<th>at 4600 hours</th>
<th>Energy Saved (kWh)</th>
<th>Energy Saved (BTu)</th>
<th>Home Equivalent</th>
<th>Cost Savings</th>
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<td>6,000</td>
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<td>450</td>
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<td>23,392,282.562</td>
<td>15,096.6</td>
<td>754,832.28</td>
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<tr>
<td>Exterior D-Pillars</td>
<td>850,000</td>
<td>4,898</td>
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<td>Bumper Brackets</td>
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<tr>
<td>Interior Garnish</td>
<td>3,200,000</td>
<td>13,911</td>
<td>686</td>
<td>14.5</td>
<td>12.0</td>
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<td>227</td>
<td>15,133,333</td>
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<tr>
<td>Head Lamp Pocket</td>
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<td>227</td>
<td>15,133,333</td>
<td>13,111,913.4</td>
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<tr>
<td>Sum</td>
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<td>23,392,282.562</td>
<td>15,096.6</td>
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</table>

Energy Saved (kWh): 6,853,877.1
Energy Saved (BTu): 23,392,282.562
Home Equivalent: 15,096.6
Cost Savings: 754,832.28
Frequently Asked Questions

- Deposition Rate: 24 to 300 cm³/hr
- Deposition Speed: 500 to 1800 mm/min
- Beam Diameter (spot size): 1mm to 5mm diameter
- Layer Thickness: 0.1 mm to 1.6 mm
- Hardness: Fully Hardened “as-quenched”
- Powder Efficiency: 40 to 70 % (product dependent)
- Post-DMD Machining: CNC/EDM/Grinding

### Comparison of Material Properties: DMD vs. Wrought/Casting

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength</th>
<th>Yield Strength</th>
<th>Elastic Modulus</th>
<th>Charpy Impact</th>
<th>Hardness</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(MPa)</td>
<td>(MPa)</td>
<td>(GPa)</td>
<td>(J)</td>
<td>(HRC)</td>
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<tr>
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<td>316L SS, DMD</td>
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<td>1650</td>
<td>9.0</td>
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<td>678</td>
<td>515</td>
<td>4.0</td>
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<td>585</td>
<td>530</td>
<td>4.5</td>
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### Wrought Alloys

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<td>197</td>
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<td>54</td>
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<td>Inconel 718</td>
<td>1650</td>
<td>136</td>
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<td>136</td>
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<td>12.9</td>
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<td>1650</td>
<td>136</td>
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<td>9.0</td>
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### Cast Alloys

<table>
<thead>
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<th>Material</th>
<th>Tensile Strength</th>
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<th>Elastic Modulus</th>
<th>Charpy Impact</th>
<th>Hardness</th>
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<tbody>
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<td>Stellite 21, cast</td>
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<td>955</td>
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<td>12.9</td>
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<td>Stellite 21, cast</td>
<td>1141</td>
<td>955</td>
<td>8.0</td>
<td>112</td>
<td>12.9</td>
</tr>
<tr>
<td>Stellite 21, cast</td>
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<td>955</td>
<td>8.0</td>
<td>112</td>
<td>12.9</td>
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</table>

### Ti-Alloys

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<th>Yield Strength</th>
<th>Elastic Modulus</th>
<th>Charpy Impact</th>
<th>Hardness</th>
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<tbody>
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<td>690</td>
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<tr>
<td>Ti-6Al-4V, wrought</td>
<td>855</td>
<td>690</td>
<td>8.0</td>
<td>112</td>
<td>12.9</td>
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<tr>
<td>Ti-6Al-4V, wrought</td>
<td>855</td>
<td>690</td>
<td>8.0</td>
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### Cu-Alloys

<table>
<thead>
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<td>Cu-30 Ni</td>
<td>217</td>
<td>180</td>
<td>12.9</td>
<td>126</td>
<td>120 HV</td>
</tr>
<tr>
<td>Cu-30 Ni</td>
<td>217</td>
<td>180</td>
<td>12.9</td>
<td>126</td>
<td>120 HV</td>
</tr>
</tbody>
</table>
H13 Impact Properties

DMD Process Overview

What Now?

Designed Material?
What Is Designed Materials?

• The material design based on performance requirement enabled by the homogenization design method
• This is a departure from conventional material selection methods where performance is limited by available material
Processing HDM Output

Construct a solid model from homogenization output

Negative CTE Structure

Green Nickel, Blue- Chromium

Completed Structure (2.4 in x 2.4 in x 0.5 in)
Test Results

Strain vs. Temperature, Test #1

Strain vs. Temperature, Test #2

Both Results in y-direction

GLOBALLY ACCESSIBLE MANUFACTURING and MAINTENANCE ACTIVITIES (GAAMA)

WHAT ARE WE PROPOSING?

• Manufacturing systems for:
  – Precision Products
    Directly from CAD by
      - combined Laser Aided Metal Addition and Subtraction
      - with Remote Control Capability
        (U.S. Patent 6,580,959)
**What can we do Together with CPMT?**

DMD Process Overview

- Apply DMD to CPMT Member products: Tools And molds with conformal cooling, On site repair, components repair like valves with cobalt free alloys.
- I/UCRC membership for Application driven basic research
- Jointly seek State and Federal programs
- DMD Will reduce lead time & Economy friendly
- DMD is Environmentally Benign
THE END

THANK YOU for your attention