Directed Energy Lasers: A Historic and Future Perspective

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Outline

- Directed Energy Introduction
- DE Threats and Solutions
- DE Laser Timeline and History
- DE Laser Performance
- Evolution of DE Lasers 2001 – present
- Fiber Laser Development
- DE Lasers and Subsystems
- High Energy Laser Roadmap
- DE Funding Profile
- Threat Defeats with Ultrashort Pulse Lasers
  - Self-focusing via atmospheric nonlinear effects
- USP Laser capability complimenting CW laser platforms
- Industrial Applications for USP lasers
- DE Industrial base challenges
- Acknowledgements and References
- Questions
Ancient Greek and Roman historians recorded that during the siege of Syracuse in 212 BC, Archimedes constructed a burning glass to set the Roman warships afire.
Electromagnetic Spectrum

The top bar shows how the electromagnetic spectrum is divided into various regions, and indicates that portion referred to as the Radio Spectrum. The lower bar illustrates the division of Federal, Non-Federal, and Shared bands for a critical part of the Radio Spectrum. Also shown are selected military uses that would be impacted by reallocating spectrum for competing commercial use.

Reference 3
Why Directed Energy

- Providing attack at the speed of light
- Precise targeting
- Rapid engagement of multiple targets
- Adjustable damage capacity
- Relatively low operational cost
- Reduced logistic support
- Relatively unlimited magazine
- Wide area coverage

Engage at the speed of light with increased magazine depth and decreased shot cost

References: Ref. 1; Ref. 2
# Directed Energy Weapon (DEW) Threats

## High Energy Lasers
- **Dwell time, Line of sight, Targeting**
- Hard kills to computers, communications, navigation, control systems, electronics
- Host Platform: land-based, mobile, ship, aircraft
- Phasers, ion cannons, particle accelerator guns
- Nuclear collisions with atmosphere – energy loss
- Nonlinear instabilities – collective beam effects
- Neutral particle beams for space

## Soft Kills
- Soft kills to computers, communications, navigation, control systems, electronics
- Interaction with atmospheric environment: turbulence, diffraction, refraction absorption, thermal blooming etc.
- Back-door attacks through gaps in metal shielding
- Propagation energy/intensity loss due to ionization and radiation
- Electrons accelerated beam shaped by mirrors, antenna focuses beam on target

## Electromagnetic Pulses
- Short pulse of energy – range of frequencies
- Complex interaction for atmospheric propagation – beam expansion and contraction
- Inherently divergent beams
- Vehicle stopping
- Out-of-band damage to circuits
- Causes burning sensation in humans without causing damage

## High Powered Microwaves & Radio Frequency
- Longer wavelength than HEL
- In-band damage to radars and communication systems
- Vehicle stopping
- Electromagnetic pulses damage electronics and create sparks that can cause explosions; large EMPs can damage aircraft, buildings etc.

## High Energy Beams
- Designed for area denial, perimeter security, and crowd control
- Non-lethal
- Millimeter wave electromagnetic energy
- Inherently divergent beams
- Shorter frequency than HEL

## Millimeter Waves
- Destructive thermal heat to electronics
- Active Denial Systems
- Causes burning sensation in humans without causing damage

## Future Theoretical Weapon
- High-energy beam of subatomic particles
- Phasers, ion cannons, particle accelerator guns
- Nuclear collisions with atmosphere – energy loss
- Nonlinear instabilities – collective beam effects
- Neutral particle beams for space
- Bremstrahlung effects – electron energy loss

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Reference 5
Types of DE Systems – HPM, LGE™, and Lasers

High Power Microwave (HPM)

Laser Guided Energy (LGE)

Lasers

References 6 (top) and 7 (bottom)
Timeline

1974 - 1993
Ground Based Free Electron Mid-Infrared Advanced Laser Chemical Laser (MIRACL)

1984 - 1999
Neutral Particle Beam Program

1990 - 2008
Tactical High Energy Laser (THEL)

1995 - 2001
MTHEL

1997 - 2004
JHPSSL Ph3

2001 - 2005
HELTD

Mobile Test Unit

CO2 Lasers
Army Tri-Service Laser

1970 - 1974

Modular Demonstration System (MADS)

1975

Army Free Electron Laser

1984 - 1999

Mid-Infrared Advanced Chemical Laser (MIRACL)

1990 - 2008

CO2 Lasers

Chemical Lasers

Solid State Lasers

Solid State Heat Capacity Laser

1998 - 2004
ZEUS

1997 - 2004
HELTD

Present

2005 - 2010
JHPSSL Ph3

Reference 8
High Energy Laser (HEL) World Pushes Every Laser Until it Hits a Limit

Reference 9

SSL: Solid State Laser
DF: Deuterium Fluoride
CO2: Carbon Dioxide
COIL: Chemical Oxygen Iodine Laser
HF: High Frequency
FEL: Free Electron Lasers
Key Contributions:
- Increased demonstrated power of SSLs from 1kW to 100kW
- Multiple SSL architectures demonstrated including:
  - Coherent Beam Combining
  - Spectral Beam Combining

Other contributing JHPSSL Orgs.
- Raytheon
- Textron
- LLNL

Navy / NG Maritime Laser Demonstrator on Navy Self Defense Test Ship

1st Ever Demonstration of 100kW Solid State Laser
OSD HEL Scaling Initiative Advances Electrically-Pumped Lasers

FLASH
Coherently-Combined Fiber Laser
50 kW class

REL1 Spectrally-Combined Fiber Laser
100 kW class

Gen-3
Distributed Gain Laser
150 kW class

Beta-1
Diode Pumped Alkali Laser
30 kW class

Reference 9
Robust Electric Laser Initiative (RELI) 2011 – 2017

Key RELI Contributions

- Size Weight and Power (SWAP)
- Laser Efficiency (Electrical to Optical power) improvements
- Power-in-Bucket Metric established

Navy SSL-TM (NG RELI)
Navy HELIOS (LM RELI)
Army HEL-TVD (LM RELI)
AF AHEL (LM RELI)
AF SHEILD (LM RELI)
Risk reduction: AF DLWS (GA RELI)
The HEL Roadmap: Mission Growth from Tactical to Strategic Missions

2019-24

Tactical Missions with current proven technology:
- DE Strike, Counter Unmanned Aerial System (C-UAS), Counter Rolling Airframe Missile (C-RAM), Counter Intelligence.

< 100 kW class

2025-30

Tactical Missions with advanced technology:
- Counter Anti-Ship Ballistic Missile (C-ASBM), Counter Land Attack Cruise Missile (C-LACM), Base Defense, Aircraft Defense, Close-Combat

2030+

Strategic Missions with advanced technology:
- Ballistic and Hypersonic Missile Defense

MW class
Directed Energy Budget

High double-digit, year-over-year spending growth in Directed Energy by U.S. to compete internationally

- **2017**: $543 Million in Annual Federal Spend
- **2019**: $1.2 Billion in Annual Federal Spend
- **2021**: $1.8 Billion in Estimated Annual Federal Spend
Defeating the Threat

USP is emerging as an enabling capability for mobile, layered air defense

Benefits of Ultrashort Pulse:
- Peak intensity at target is 1 BILLION times greater compared to Continuous Wave (CW)
- Produces nonlinear effects not possible with CW
- Single shot takes out sensors and electronics
- Less energy required = more portable and dynamic

USP Differences from Continuous Wave:
- Lighter, smaller, more portable, and provides improved lethality
- Size, Weight, and Power (SWaP) reductions by orders of magnitude
- Enables multiple damage mechanisms and reduced engagement time

Sensors
- Cameras
- Accelerometer
- Gyroscope

Electronics
- RF Links
- GPS
- Control and Guidance
Why USP is used for LGE and Threat Defeat

Peak Power = Energy / Time

- Non-Pulsed
  \[ 1 \text{ J} / \text{S} = 1 \text{ W} \]

- Ultra-Short Pulse (100 fs)
  \[ 1 \text{ J} / 10^{-13} \text{ S} = 10 \text{ TW} \]

- U.S. Electrical Output Power Capacity
  \(~1 \text{ TW}\)

Effect of High Peak Power Laser Pulse in Air

Laser Filamentation Allows for Ionizing Intensities over Long Ranges

1. High peak power laser pulse leads to **self-focusing** through Kerr nonlinearity
2. The very high intensity pulse **ionizes the air** and the resulting plasma density distribution acts as a negative lens
3. The cycle repeats so that the beam propagates without diffraction leaving a trail of plasma and ions in the path

\[ \text{Laser “Filaments”} \]
USP Damage Mechanisms

Conventional Divergent Beam

Self-Focused Beam

RF Jamming

EO Sensor Damage

Thermal/Mechanical Damage
USP Lasers will compliment CW Capabilities

**Ultrashort Pulse (USP)**

- Laser engagement on-the-move
- Uninterrupted operation
- Compact, modular capabilities
- Helicopter (Chinook) mobile
- Peak Laser Power Output: 1 TW
- Laser Electrical Power Consumption: ~1 kW
- Laser System Weight: ~55 lbs.
- Overall platform weight: ~5500 lbs.
- Laser Weapon System Volume: ~72 cu ft

**Marine Air Defense Integrated System (MADIS)**

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**Continuous Wave (CW)**

- Stationary laser engagement
- Limited duration operation before recharge
- Extensive laser system component footprint
- Not air mobile
- Peak Laser Power Output: 50 kW
- Laser Electrical Power Consumption: ~200 kW
- Laser System Weight: ~550 lbs.
- Overall platform weight: ~22 tons
- Laser Weapon System Volume ~1280 cu ft

**High Energy Laser Mobile Test Truck (HELMTT)**
Advanced USPL Commercial Applications

- LGE™ provides a tailorable electrical power source and additional fields that provide control over the plasma generation, transport, deposition, and secondary effects such as heating and surface modifications.

- USPL provides high resolution subtractive and material modification processes that allow for very fine detail without adding deleterious heating unless required.

- Intense laser field interactions, external electric and magnetic fields, plasmas generation and control, bulk material processing and transport, surface modifications and fine subtractive processes are all inherently enabled by the combination of LIPCTM/LGETM/USPL.
Directed Energy Industrial Base Challenges

Development and supply chain maturation for laser system components

- High Damage Threshold Optics (> 1 μm)
- Adaptive Optics and Advanced Jitter Control
- Power and Thermal Management
- High Volume Manufacturing of Diodes and Laser Gain media
- Track and Beam Illuminator sources (> 1 μm)
- Fire Control Modules
- Laser Beam Propagation and Laser-Material Interaction (\(\lambda\) and \(\Delta t\))
- Platform Traceable Laser Metrics
- Standardization and Quality Control
- Ruggedization
- Utilization in public spaces
ACKNOWLEDGEMENTS

- Patrick Williams and Stephen McCahon, PhD – Applied Energetics, Inc.
- The Directed Energy Professional Society (www.DEPS.org)

REFERENCES

1. Artistic interpretation of Archimedes' mirror used to burn Roman ships. Painting by Giulio Parigi, c. 1599.
Questions?

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