State of art in the science and Technology of Electrical Discharge Light Sources

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Light Sources Workshop
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Matsuyama, Japan

C.P.A.T. - U. Toulouse III
http://cpat.ups-tlse.fr
Producing Artificial Light before electricity

**HOT**
- Incandescence
- ✓ Fire
- ✓ Torches
- ✓ Candles
- ✓ Oil lamps
- ✓ Gas lamps

**COLD**
- Phosphorescence
- ✓ Tribo- & thermo-luminescence
- ✓ Lightning
- ✓ Bio-luminescence

This is an idea...
Producing Artificial Light using electricity

Electric Arc

Carbon arc

Humphry Davy & Michael Faraday

1812

Incandescence

Carbon filament

Thomas Edison

1878
The Family of Electric Light Sources

- Selective Filter
- Halogen
- Classic W-wire
- Incandescence

- Clusters

- Operating Pressure

- Power supply mode

- Electrical Discharge

- Luminescence

- Type of Spectrum

- L.E.D & O-LED

- Field emission

- Solid State
Light sources are everywhere

- Indoor lighting
- Monument lighting
- Industrial applications
- Urban Lighting
- Vehicles & Transport
- Display panels
- Urban Lighting
Some Figures

- 2 100 TWh electrical power consumed every year for lighting
- 10%-15% worldwide energy production
- 200 billion Euros spent for energy per annum

- 30 billion lamps operate every day worldwide
- 10 billion new lamps are produced per annum

- 1 800 millions of tons of CO₂ per annum
- 80 tons of Hg-contaminating wastes are collected in France per annum
- Light pollution of the skies

(Mils, RL-5, 2003)
Lighting is a rapid growing sector worldwide

Fastest growing technology markets
(Hagler Bailly, Idc)

Turnover (Billion US$)

1996  2006  2016

Lighting: 16%
ASDs: 17%
Building controls: 16%
Motors: 14%

Needs are also increasing:

OECD predicts that needs will be multiplied by a factor of 2 within next decade

This figure don’t includes “periphery” Industry and non-lighting applications
Problem:
Many major products are in Maturity & Saturation

Technical Systems exist in a lifecycle characterized by 4 distinct phases:
- **Childhood**: New Invention or new technology is becoming ready for market
- **Growth**: Product or Technology is improved and increases market share
- **Maturity**: Product/technology is highly Optimized and all potentials activated
- **Saturation**: Cost structure becomes ineffective, products begin to disappear

To be successful it is crucial to know the status of each product and the transition to new generations

S-Curve Product Lifecycle Analysis
Question:

What is the answer? It is rather complex!
To see: Using a photoreceptor in order to detect, to locate and to identify an object illuminated by a light source.
Some definitions (the photoreceptor)

The eye perceives different wavelengths and the brain "see" colours.

An object appears coloured by selectively reflecting or absorbing various wavelengths of incident light.

Brightness

1 radiant watt (W) emitted at 555 nm equals to 683 lumens (lm)

Efficacy (\(\eta\))

\(\text{lm/W}\)

Colour rendering index (CRI) & Colour Temperature

The eye perceives different wavelengths and the brain "see" colours.

The eye perceives different wavelengths and the brain "see" colours.
An example of "Colour"...
Illuminance 800 lx

$T_{cp} = 5000$ K
The quality of a light source may be defined only for a given application...

- High Pressure Sodium lamp (Ceramic envelop)
- High Pressure Sodium lamp (Quartz envelop)
- "White" High Pressure Sodium lamp
- Incandescence

CRI: Color Rendering Index

η: Efficiency
The "10 commandments" for a good lamp

* Produce light by using a minimum input power

* Produce "good light"
  - Spectrum
  - CRI
  - Colour Temperature

* Produce stable light
  - Fluctuations
  - Maintenance

* Produce instantaneous light

* Avoid any pollution
  - Heat
  - UV
  - EMI
  - Toxic Materials

* Be interchangeable with other lamps

* Be light and compact

* Have a long lifetime

* Have a minimum cost

This is utopic...
OK!

What is the next challenge for the lamps??
Progress of luminous efficiency

(J. Waymouth, ALITE-95)
Research and development are “key” issues

Constraints

Legal Socio-Economic...
Energetic Environmental...

Power Supply

Light Source & Optics

Electrical Network

Control & Monitoring

Electrical Engineering
Signal treatment
Control science...

Physics Chemistry Materials...

Physiology Ergonomic Psychology...

Complexity = cross discipline
But many other issues are also crucial…

What next?

New Standards & Metrology
Inciting Measures
Extra Legislation
Market knowledge
Technological Development
Social knowledge
High Quality Research
Training

Innovative Lighting Systems

Energy Effective
Environmental Friendly
User Friendly
High level Quality of life
OK!
Where are the challenges?
Low pressure lamps

Phosphors (this is a major challenge)
How to avoid ~50% phosphor conversion loss?
- Quantum splitting phosphors – 2 visible photons for each UV photon – some progress
- Generate white light directly in visible region by using high volatility molecules

Shape and Quality
Some mileage left here for innovation
Heliax CFL (GE)

Power Electronics
- Enhancing operating conditions
- Deep dimming
- Permanent monitoring

Avoid Mercury!

Lamps for special applications (backlighting)
- Phosphor
- wire
- tube
- Cold cathod

HARISON
Colour control

- Gas mixture
  - Pumping port: Positive column
  - Nearby the cathode region
  - Discharge in pure Ne
  - Discharge in Ne with Xe trace
  - Optimized discharge in Ne-Xe mixture

- Segregation

- Mixture: Hg + Ne
- Publicity Lighting
- Automotive

Sinusoidal Impulsionnel

Courant1

Temps

Courant2

Temps
High Pressure lamps

White colour required with less Hg...

Ceramic MHLs
- Power range: 20 - 400 W
- Efficacy: 70 -100 lm/W
- CRI: 86 - 95
- T : 3000 - 4500 K
- Life span: 7000-16000 h

- Shape & compactness
- Colour, Colour Quality & Stability
- Lifetime and Reliability
- Electronic gears
- Dimming with adaptation to vision requirements
- Rapid starting and warm-up

150-400 W : direct concurrence for SHP for urban lighting
20W-70 W : direct concurrence for inc. lamps for given applications
And more especially automotive...

- **Environmental issues**
  - banning Hg, Cd, Pb, Cr (VI), ... from cars
  - Effective: 01.07.2003 (new cars), 01.07.2007 (old cars)
  - EU: 8 Mio. t of waste per year from 12 Mio. cars
  - corresponding to the order of kg Hg from discharge lamps

- **Market issues**
  - HID

- **Hg-free**
  - D2S
Electrodeless lamps

Sulphur lamp

This is an important Challenge sector!

**Table: Performance Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Electrodeless</th>
<th>Fusion (US)</th>
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</thead>
<tbody>
<tr>
<td>Power (W)</td>
<td>1385</td>
<td>3400</td>
</tr>
<tr>
<td>Intensity (lm)</td>
<td>134000</td>
<td>410000</td>
</tr>
<tr>
<td>Efficacy (lm/W)</td>
<td>97</td>
<td>120</td>
</tr>
<tr>
<td>$T_{col}$ (K)</td>
<td>5400</td>
<td>6500</td>
</tr>
<tr>
<td>CRI</td>
<td>79</td>
<td>86</td>
</tr>
</tbody>
</table>

**Graph: Sulfur Lamp Spectra**

- Visible: 61%
- UV: 10%
- IR: 1%
- Heat: 28%
- Fusion (US) spectrum compared to Sun, EYE RESPONSE.
Excimer & DBD lamps (General lighting & signs)

- General lighting
- Advertisement
- Backlighting

The biggest worldwide advertisement display (3 000 m², 900 PLANON™)
Dutch telecommunications company, KPN, (Rotterdam).

Gas: Xe (Hg-free)
Pressure > 100 Torr
Thickness < 10mm
Lifetime > 10 000 h

Osram Planon DBD and gear

Osram GmbH
Excimer lamps
(special applications)

Industrial Applications
- Photochemistry/Polymerization
- Surface Traitement
- Water Purification
- Dermatologie & Medecine
- Photo-catalysis

Flexible Geometry
Light Emitting Diodes

**Market**

<table>
<thead>
<tr>
<th>Year</th>
<th>Market Size ($ Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>120</td>
</tr>
<tr>
<td>1999</td>
<td>690</td>
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<tr>
<td></td>
<td>1740</td>
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The light source of the future... Dream or reality?

LED versus Incandescence
Some Positive points

- High brightness
- Excellent colours
- High efficacy (for some colours)
- Low dimensions & weight
- High lifetime (>25,000 h)
- No theoretical limit for efficacy

Craford’s law

- LED luminous flux per package (lm)
- LED lamp price per lumen (S/lm)

Progress in light extraction

- Absorbing Substrate (1991)
- Transparent Substrate (1994)
- Large Junction (1998)
- Truncated Pyramidal (2000)

Flux progress: ~3 x ~5 x ~1.5 x
Problems & Challenges

- Low power (W)
- Directional lighting
- High cost for a global system
- Severe colour changes with Voltage & Current
- Sensible in temperature/humidity
- High complexity system control
- Poor production reliability in line

Challenges:
1. Enhance flux maintenance
2. Close the gap from green to yellow
3. Enhance efficacy by 50% @ every \( \lambda \)
4. Enhance line production reliability
5. Increase emitting surface
6. Enhance system control
White LEDs the Challenge!

LEDs are compact, mechanically stable, need only low voltage operation, can be dimmed, and have long life time.

White LED

White light = Yellow + Blue

Epoxy

Yellow emitting Phosphor

Blue Chip

SMT-Topled®

LED-Emission + Excitation

Emission from Phosphors

Emission Wavelength

400 500 600 700 nm

US congress voted in 2002, $470 million program for white LEDs for general lighting

Objective: 200 lm/W white LED by 2011!

Today: 25-30 lm/W

(Courtesy of Osram GmbH)
O-LEDs

- High resolution
- High Colour Quality
- Flexible, bendable...
- Excellent mechanical properties
- Low weight
- Small dimensions
In conclusion

Light is the most visible human product

20th Century was the century of the "Electron"...

Light is the most visible human product

The 21st Century will be the Century of the "Photon"

Thank you!