Development of New Large-Area Photosensors in the USA

@BURLE – classical PMTs *(separate talk)*

@UC Davis:

(1) ReFerence Flat Panels for mass production

(2) Light Amplifiers (flat and spherical)

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Development of Novel Photosensors

at UC Davis

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1. The Motivation

2. Problem #1: Mr. Liouville $\rightarrow$ Irreducible Illuminated Area

3. Problem #2: Industrial Mass-Production Needs a REAL MARKET (not only physics)

4. Solutions

ReFerence Flat-Panel Photosensor

The Light Amplifier Concept (flat and spherical)

New Markets
SEARCHING FOR EXTREMELY RARE AND WEAK RADIATION SOURCES

PARTICLE ASTROPHYSICS
(new generation of experiments)

PREVENTION OF NUCLEAR TERROR
Future projects to study very rare phenomena

- **Proton decay, Neutrino Physics and Astrophysics**
  UNO, MEMPHIS, HYPER-K, Kilometer-Cube, also deep-sea Nestor, Nemo, Antares, etc.

- **Gamma-ray Astronomy** – a study of faint and/or variable sources requires telescopes with low detection threshold & wide acceptance angle (huge photosensor area)

- **Ultra-high energy cosmic rays** (>10^{19} eV)

- **Double beta decay**
2000-2004:
Advanced Detector Research Award DOE/HEP:

“Novel Highly Sensitive Photosensor Technology for Inexpensive Large Area Cherenkov Detectors”
~$350,000

2002-2003:
Purchased >$2M equipment from the Candescent FE flat-panel TV factory

2004:
Purchased a production unit (exhaust station) for 18-mm night-vision image intensifiers (Gen-2), with the MANUAL (Litton Co.)

NEW 2004-2007:
National Nuclear Security Administration (NNSA/DOE), Office of Nonproliferation Research and Engineering:

“Development of ReReference Flat-Panel Photosensors for Novel Super-Large-Area Radiation Detectors”
$750,000
Few Remarks on Nuclear Terror

• Explosion of real nuclear weapons in big cities – an expected event
• Leakage of
  – Weapon-grade fissile materials
  – Nuclear bomb technology
• ~1994: a real nuclear bomb may be created from Reactor-Grade Plutonium
• PROBLEM: N-Bombs are only weakly radioactive

➡ Large-Scale monitoring is needed, with simple, pixelized, mass-produced super-large-area radiation detectors
(passive detection; neutron-activation; muon tracking)
Sensitivity for the detection of very rare phenomena

Very Large Volumes/Areas

‘Natural’ Transparent Media (Water, Atmosphere, Ice, +GdCl)

PHOTOSENSORS

No other choice than
Several unconventional photosensor concepts

• **Flat-Panel “ReFerence” Camera Concept (Patented)**

• **“Light Amplifier” concept, development just started**
  – SMART PMT (Phillips) → modified configuration
  – ReFerence panels → scintillator (fiber) readout

• **“SIMPLE” Imaging Camera Concept, project idling, for EUSO, OWL, but also ground-based applications**
  Patent Pending, project pending

• **Deep-Sea Photosensor (a new idea, but have no time...)**
Cherenkov angle in water
\(~40\) degrees

\(\Rightarrow\) The “Camera” must be large

The Unbeatable Reality of Mr. Liouville
Irreducibly Large Illuminated Area

Photosensors with very strong internal information concentration

Vacuum

( photon $\rightarrow$ photoelectron $\rightarrow$ no more Liouville )
OBJECTIVES

1. Large Photosensor Area Coverage
   • High Quantity
   • High Quality
   • Low Price

→ Industrial Mass Production

2. High Detection Efficiency and S/N
   (collection and quantum efficiency)
OBJECTIVES

1. Large Photosensor Area
   - High Quantity
   - High Quality
   - Low Price

2. High Detection Efficiency and S/N

WHY NOT ACCOMPLISHED ALREADY?????
Semiconductor Photosensors

→ developed very successfully

(but pixel sizes and areas far too small)

Vacuum Photosensors

(suitable for large-area applications, strong area reduction) did not develop significantly since mid-1960s

Why?

Because of the Vacuum?
Development of Other Vacuum Devices

~1960

~2000

Price: ~$2,000 per m²
1. Dielectric
2. Patterned Resister Layer
3. Cathode Glass
4. Row Metal
5. Emitter Array
6. Single Emitter Cone & Gate Hole
7. Column Metal
8. Focusing Grid
9. Wall
10. Phosphor
11. Black Matrix
12. Aluminum Layer
13. Pixel On
14. Faceplate Glass
Flat Panel Camera – wishful thinking:

“Continuous” Hybrid Photon Detector (HPD)

PiN, APD, something else

window

electrons

cavuum

Reflection-Mode Photocathode
Problem #1 – Electron Optics

This doesn’t work!
Problem #2 – Mechanical Stability

(flatt plates need supports)
Flat-Panel Pixelized Camera Configuration →

provided by the Reference Photosensor Concept
Ideal Light Concentrator
(takes the maximum of Liouville!)

Optimal Electron Lens

Photon

PIN, APD, or “Something Else”

Photoelectrons

Photocathode

Optimal Electron Lens
Very Important: Hexagonal Packing

Entrance Aperture

Photocathode
Flat-Panel Honeycomb Sandwich Camera Construction

Industrial Production (no glass blowing etc.)
Intrinsic Mechanical Stability, Low Buoyancy,..
PROTOTYPE DEVELOPMENT

UNSEALED 1-PIXEL

CYLINDRIC

2001-2002

HEXAGONAL

2003

SEALED PANELS

(7 pixels, 5 inch)

SEALED with In/Au

SEALED with SOLDER GLASS

Equipment (Candescent, Litton Night Vision) ~$2M
3\textsuperscript{rd} ReFerence Prototype

3” diameter, single pixel

(successfully tested – see below)
Strong signal concentration, factor $\sim 1500$

(one of our goals)

Replaces the entire Dynode Column!

Provides $\sim 100\%$ Collection Efficiency!

- APD
- Scintillator + Fiber (both of small and comparable diameter – transmission efficiency)
From Tubes to Large Flat Panels
Reference Panel Prototype (under construction)
Reference Panel Prototype (under construction)
Currently Aluminum – ultimately GLASS
Base pressure ~6×10^{-11} Torr

Evaporation Chamber
Sealing Chamber
Load-lock Chamber
TRANSFER SYSTEM
For 5” prototypes
Cs, Na, K dispensers
Sb evaporator
Mass spectrometer
Photocurrent monitor
Cs, Na, K dispensers
Reflection Mode vs. Transmission Mode

Extension into “blue & UV”

Quantum Efficiency

~30-43% QE bialkali
~190-450 nm
(Hamamatsu side-on PMT R7517)

Wavelength
PHOTOMULTIPLIER TUBE
R7517

High Q.E., Bialkali Photocathode
28mm (1-1/8 Inch) Diameter, 9-Stage, Side-On Type

FEATURES
● Spectral Response ........................................... 185 to 760 nm
● High Cathode Sensitivity
  Luminous .................................................. 160 μA/Im Typ.
  Radiant at 420nm ....................................... 105 mA/W Typ.
  Quantum Efficiency at 220nm ....................... 40% Typ.
● High Anode Sensitivity (at 1000V)
  Luminous .................................................. 1600A/Im Typ.
  Radiant at 420nm ...................................... $10.5 \times 10^5$ A/W Typ.

APPLICATIONS
● Fluorescence Spectrophotometers
● Fluorescence Immuno Assay
● SO$_2$ Monitor (UV Fluorescence)
Photocathode Cooling - Diminished Dark Current

Thermionic emission [e/sec/cm²]

-20°  0°  20°  40°

Cooling

InGaAs

S20

Carlsbad NM

Cooling (Peltier)
VERY EFFICIENT MAGNETIC SHIELDING

Slow electrons

e.g. UNO with Magnetic Field (???)
“Light Amplifier” Concept

Scintillators + fiber optics

NO electronics inside!!

Resolution determined outside!!

READOUT ➔

APD array
Spherical LIGHT AMPLIFIER STUDIES

SMART PMT, QUASAR

1 photoelectron $\rightarrow$ >15 photons in APD
SUMMARY

• The goal: Inexpensive Industrial Mass Production (<$2000 per sq. meter)

• Large New REAL Markets (not physics), we are funded already for/from one of those

• Fully functional 7-pixel prototype in 2-3 months (to demonstrate the panel concept, not yet for excellent performance)

• All-glass industrial prototypes ~by the end of 2005