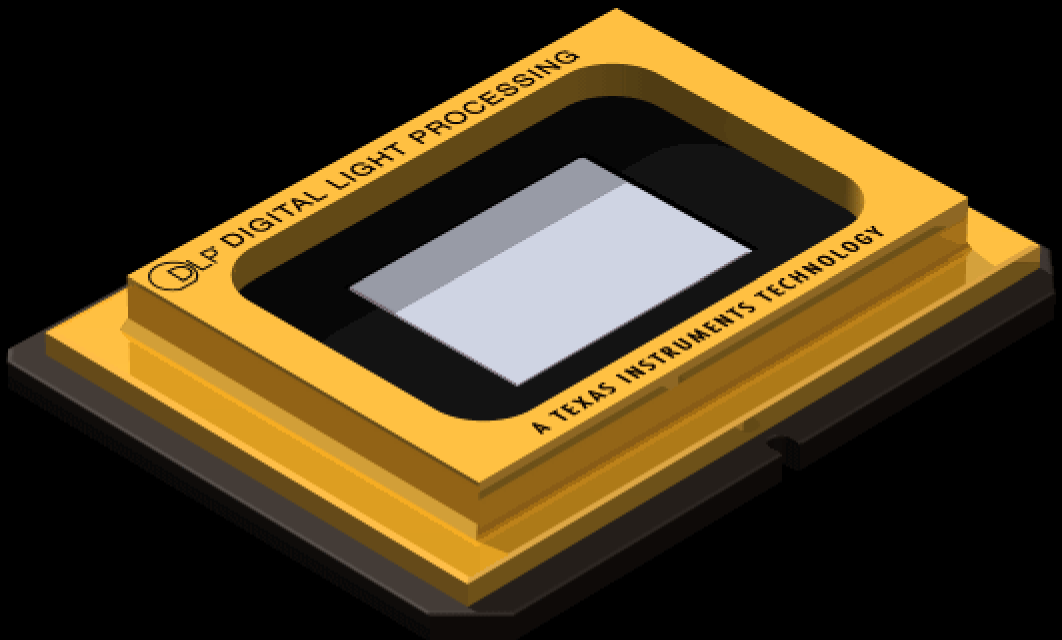
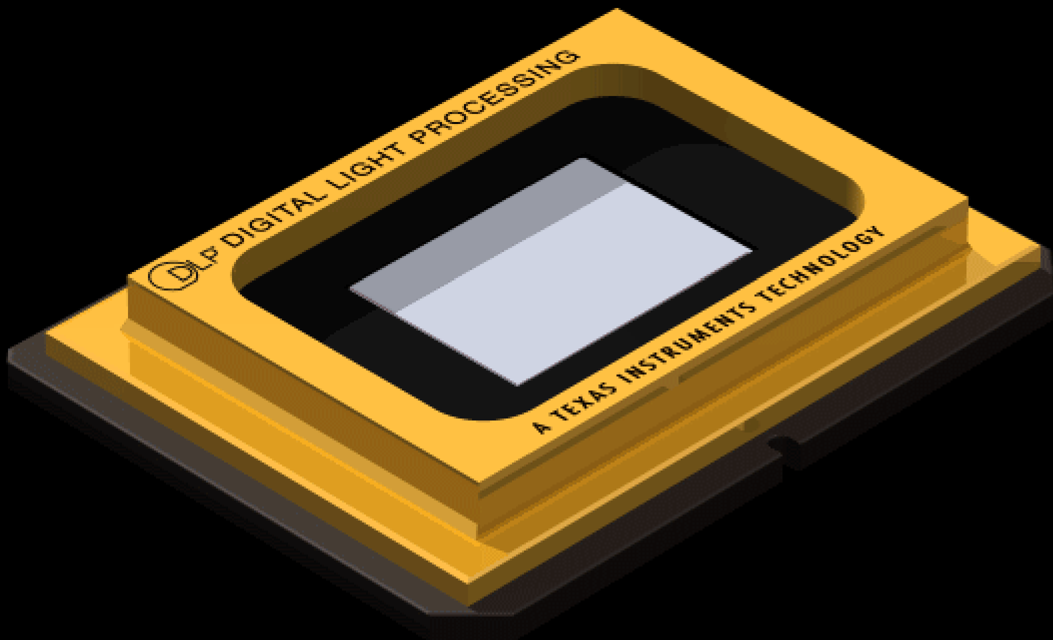
The Digital Micromirror Device

A Historic Mechanical Engineering Landmark

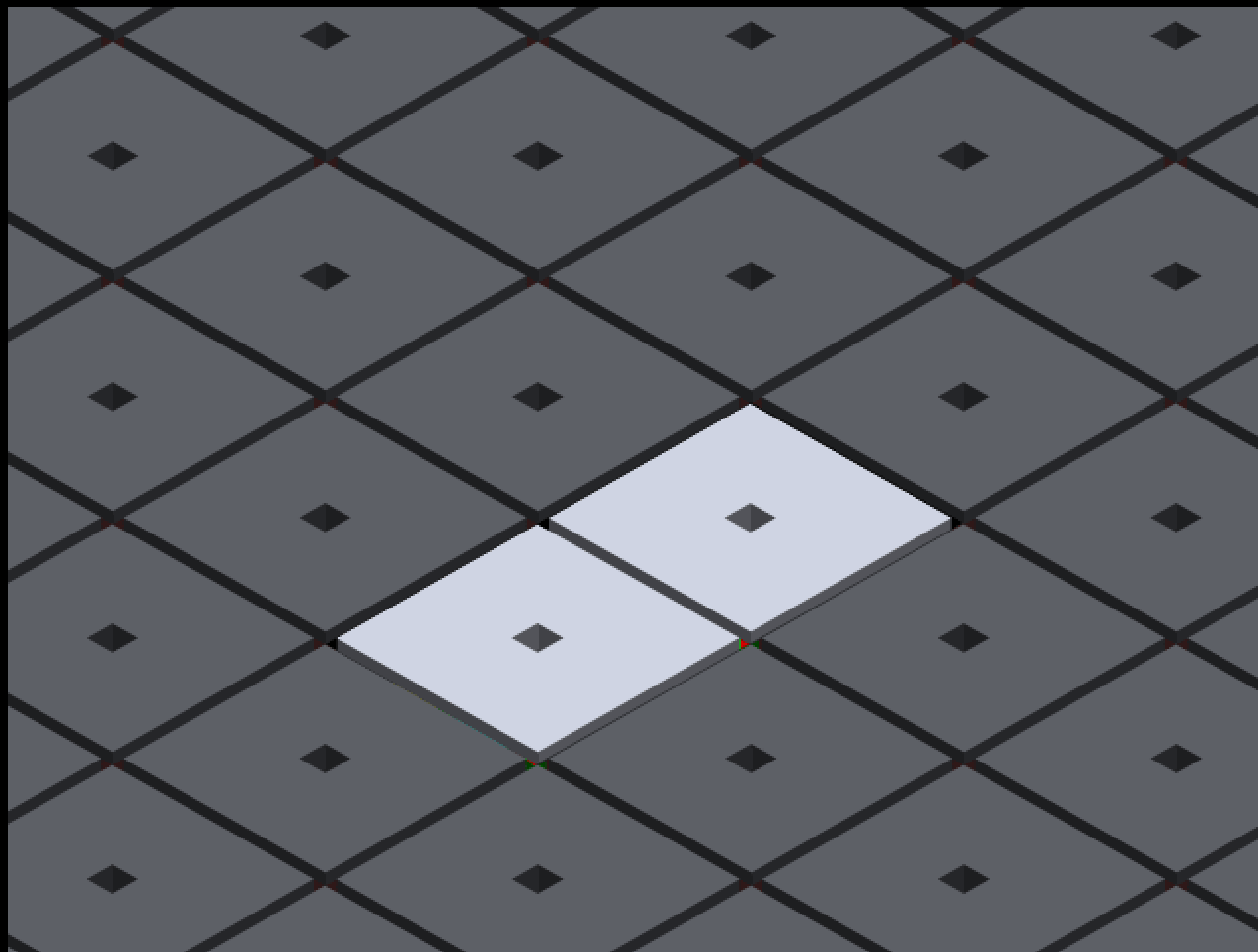
How DMD Technology Works



How DMD Technology Works



How DMD Technology Works



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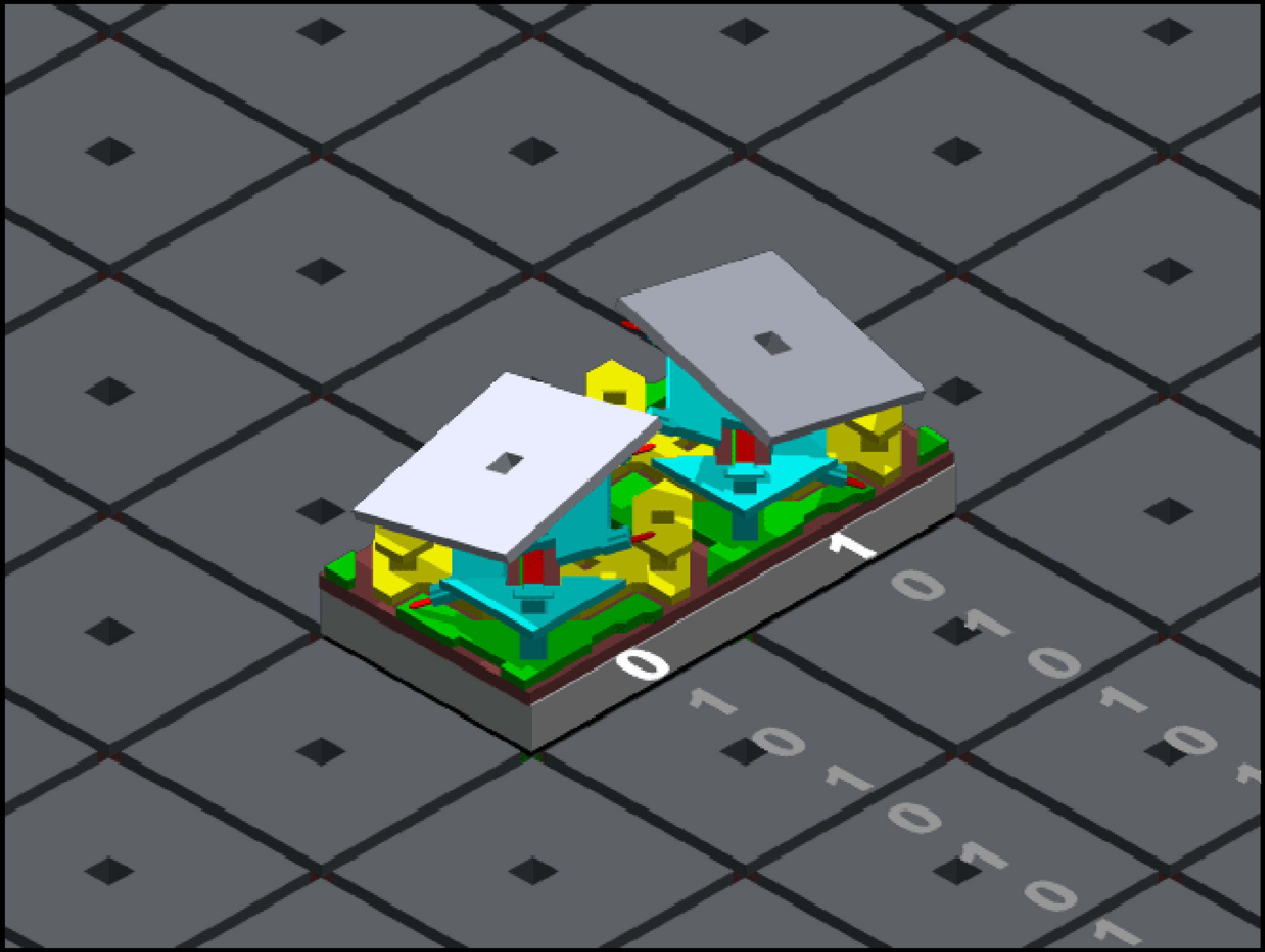
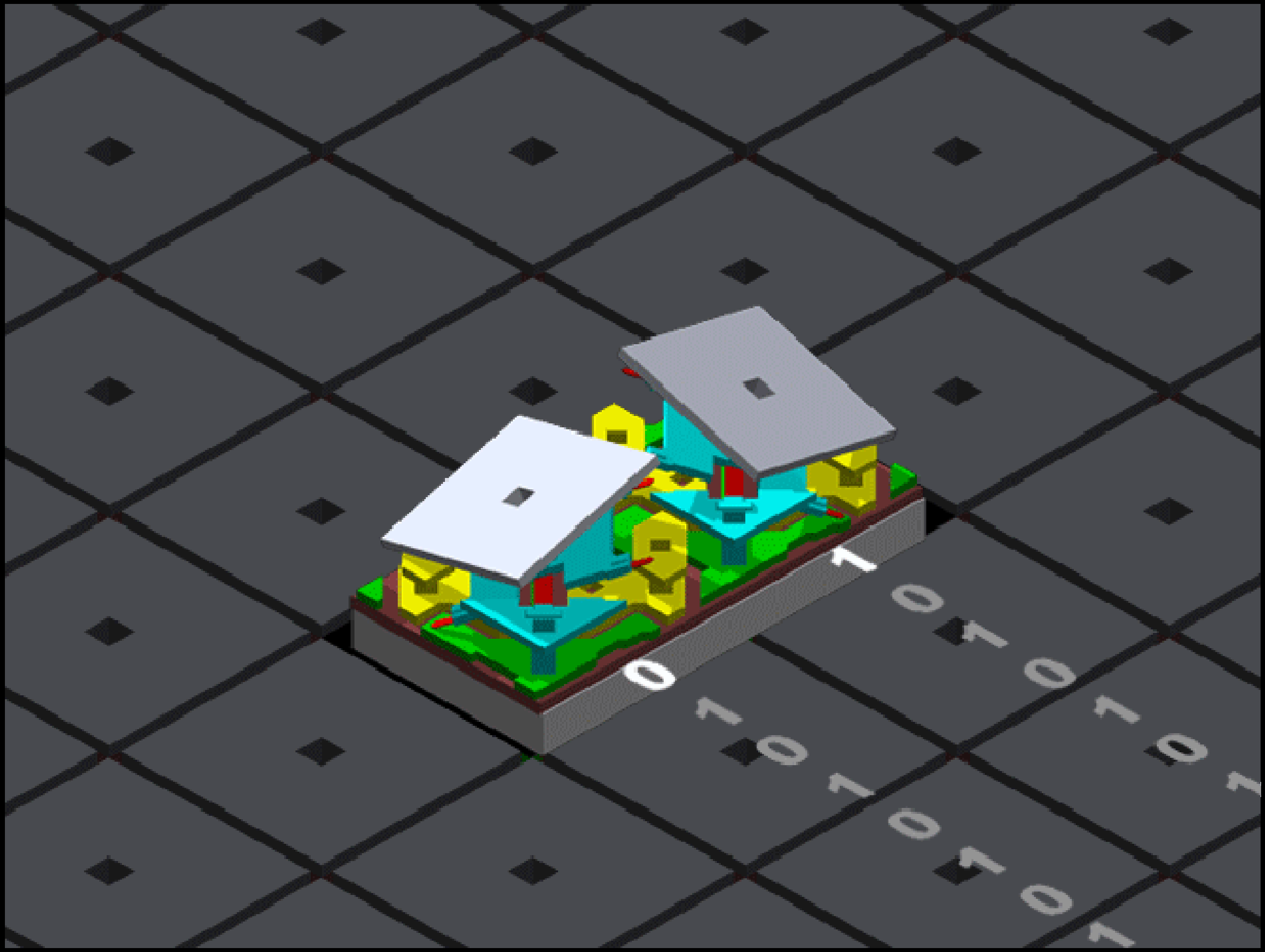
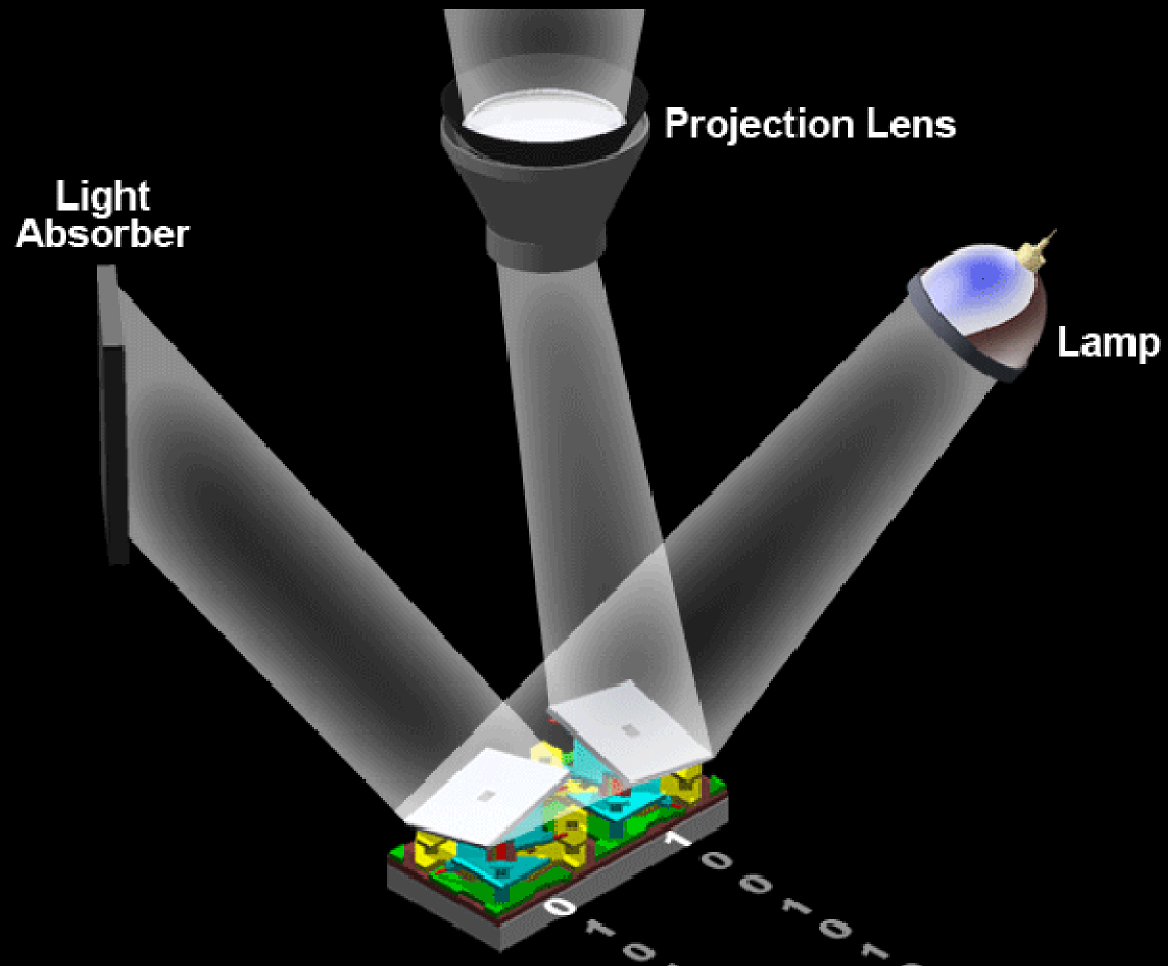


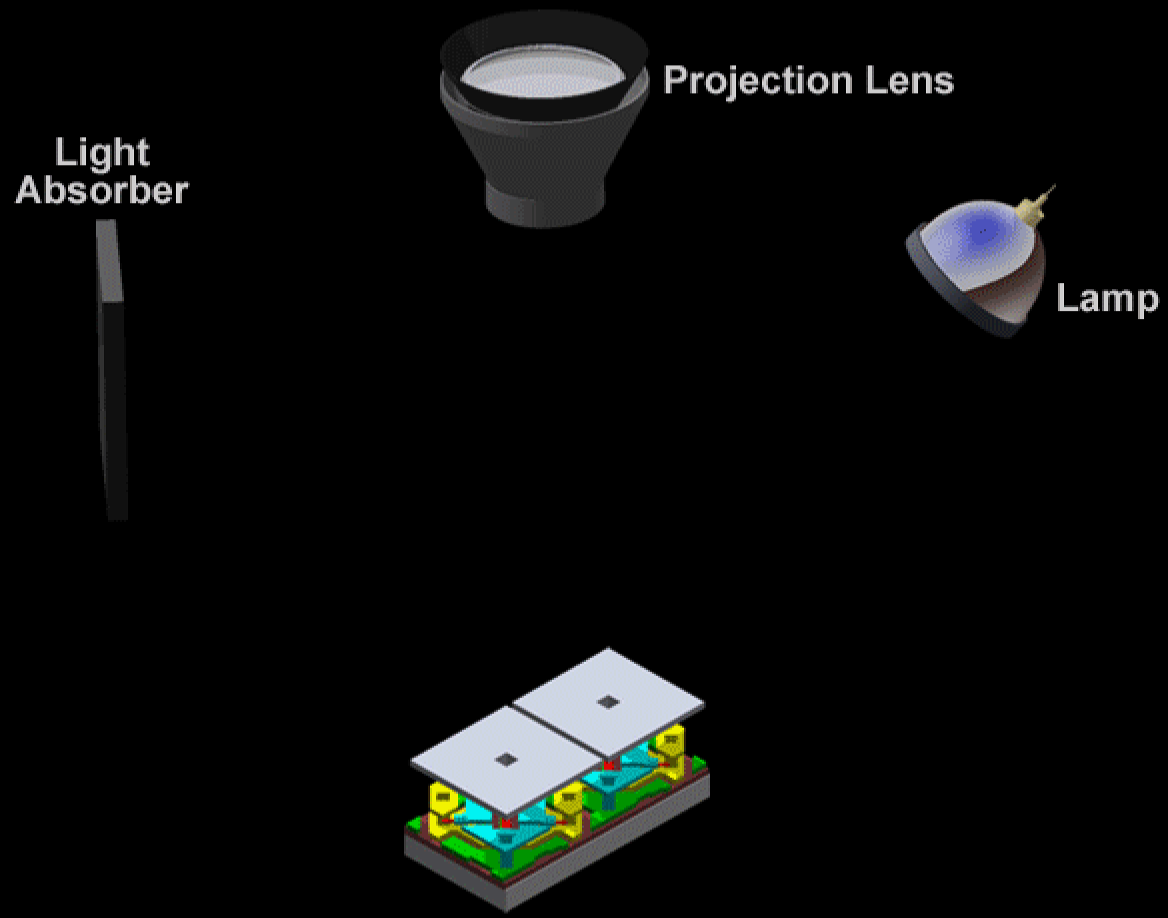
How DMD Technology Works



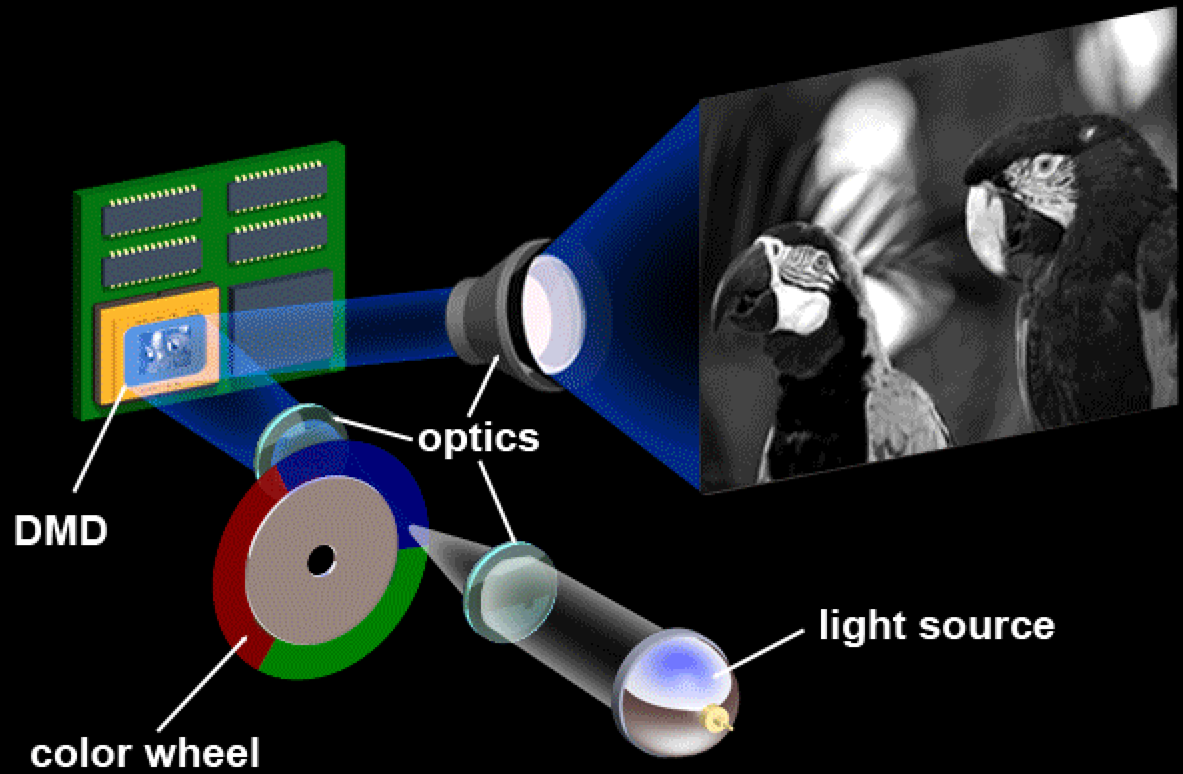
How DMD Technology Works



One Chip Solution

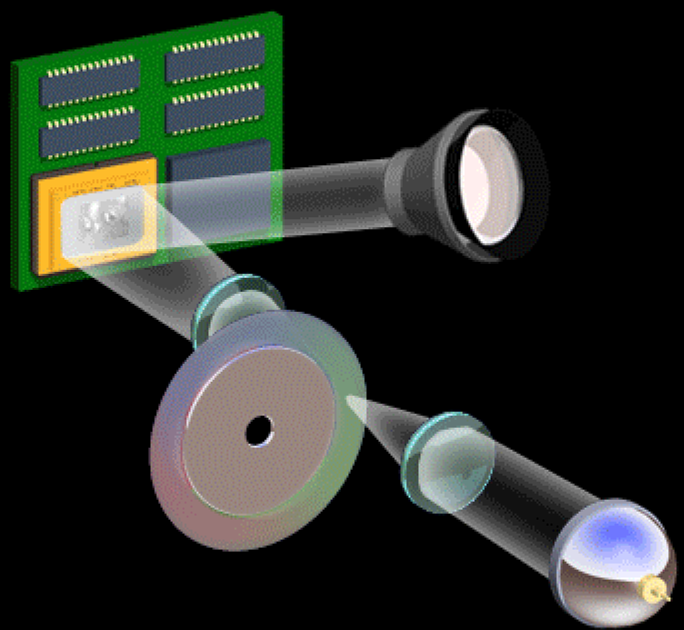


One Chip Solution

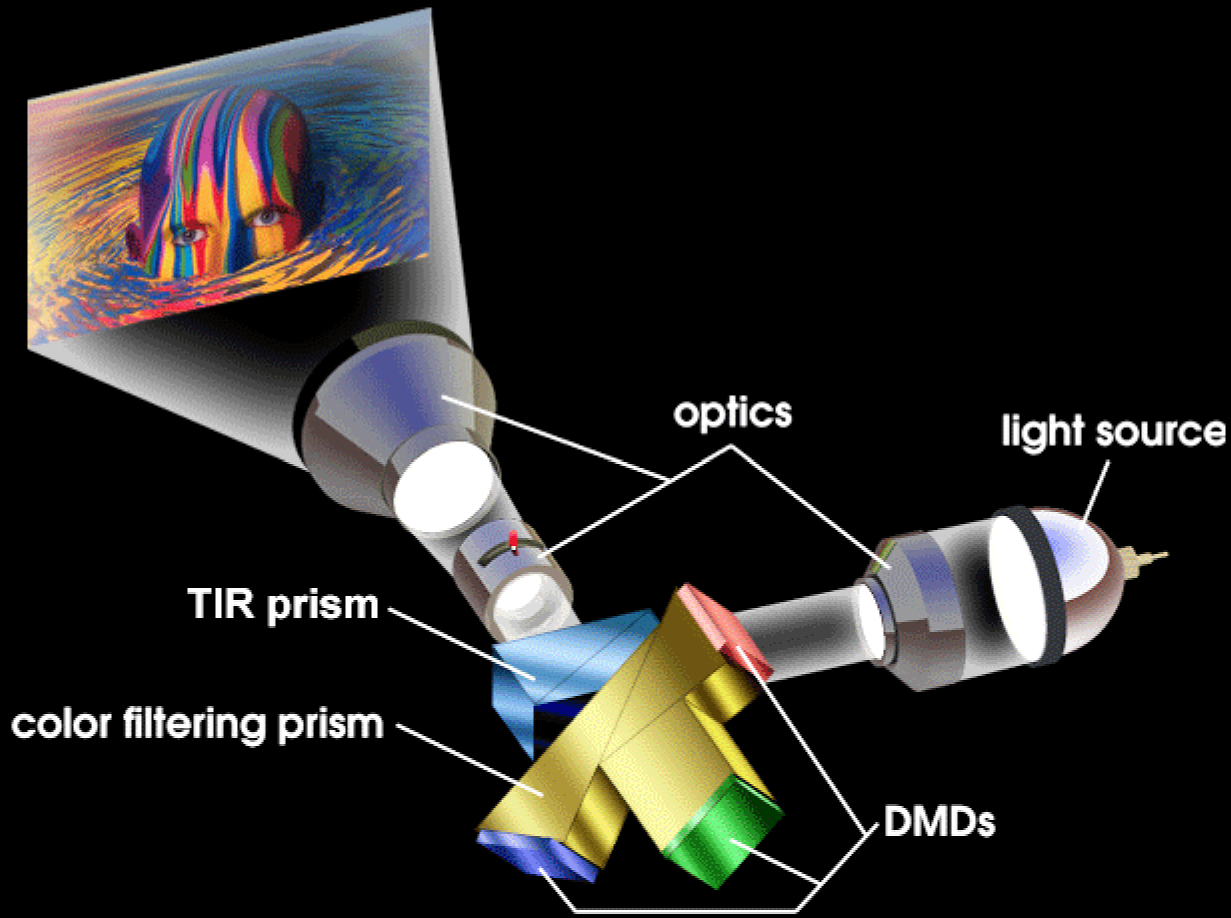


DLP technology for the business and the home

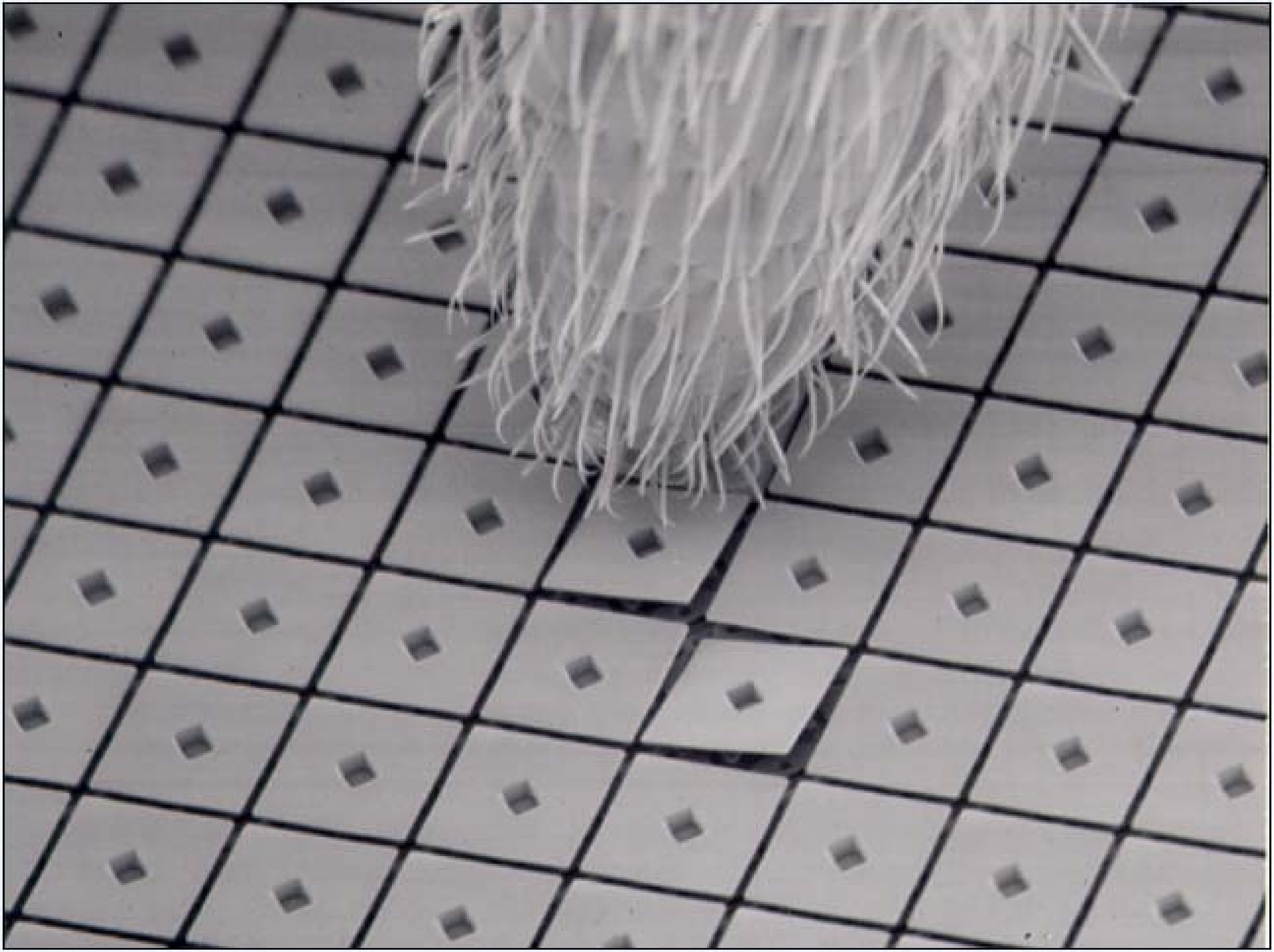
One Chip Solution

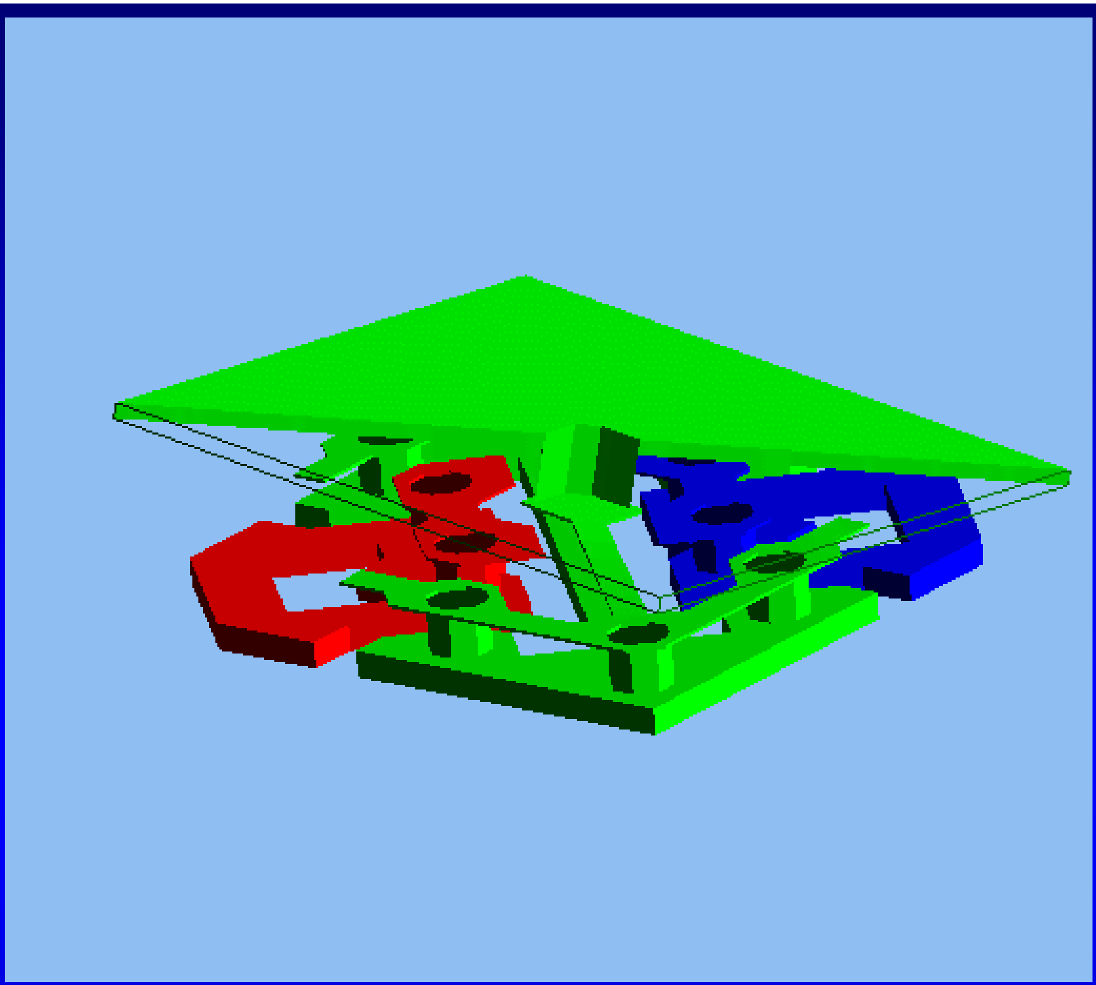


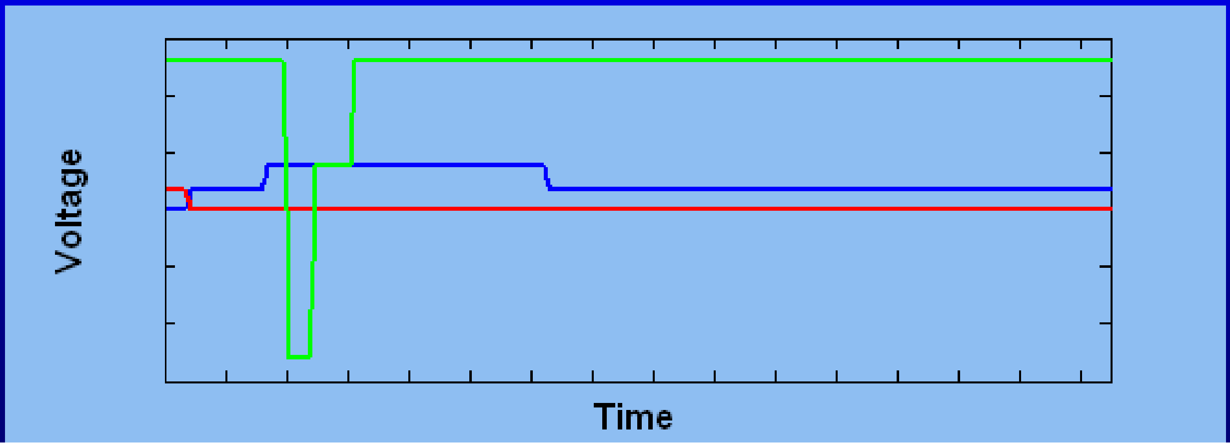
Three-Chip Solution



DLP technology for commercial and digital cinema applications






Voltage
Time

1987 Bistable DMD (basis for all future DMD devices)

Digital Bistable DMD

A new digital DMD concept, called the bistable DMD has been developed. It features digital, large angle deflections (10 degrees) at low address voltage levels (5 to 10 volts). This new device is based on the buried hinge, torsion beam DMD, but uses the new concepts of bistability, differential bias, and soft landing to achieve simultaneously, large angular deflections, low address voltages and improved deflection uniformity.

A cross section of the bistable DMD, taken perpendicular to the torsion rod axis of rotation, is shown in Figure 1. There are two underlying control electrodes and two landing electrodes symmetrically disposed about the centerline defined by the axis of rotation. The torsion beam has two stable states, shown in Figure 1 as the two landing angles $\pm\theta_L$, designed to be ±10 degrees.

Both landing electrodes are electrically connected to the torsion beam, which in turn is driven at the so-called "differential bias" level (-50V nominal). The control electrodes are driven with complimentary low voltage signals (0,+5v) and are used to select the desired bistable state (±10 degrees). The differential bias is provided by a single bus connected to an off-chip driver, hence only the low voltage control signals are switched by on-chip circuitry.

The control electrode voltages are too small by themselves to cause more than a fraction of a degree of rotation of the torsion beam. The action of the much larger differential bias is to multiply the effective torque produced by the control electrodes and to make the torsion beam bistable with minima in the energy at the two landing angles.

Non-destructive landing is achieved by utilizing landing electrodes which are biased at the same potential as the torsion beam. As the beam "lands" or touches the landinng electrode, no electrostatic discharge or welding is possible. Also there is no large attractive torque buildup as in conventional DMD's. Because the beam landing is both "soft" and free of electrostatic discharge, contact wear is reduced to negligible levels over the lifetime of the DMD.

The bistable DMD not only combines large angular deflections with low address voltages, but it also features dramatically improved deflection uniformity over its analog counterpart. The deflection nonuniformity of the bistable DMD is linearly related to and limited only by the air gap thickness nonuniformity, on the order of 1 percent. The analog DMD on the other hand must be operated in a very non-linear regime in order to achieve large angle deflections, and therefore its deflection uniformity is sensitive to small changes in hinge stress, hinge compliance and air gap thickness.

Applications for the bistable DMD include electrophotography and optical crossbar switching. A patent disclosure and the photomask design are in progress.

LJH:4/22/87

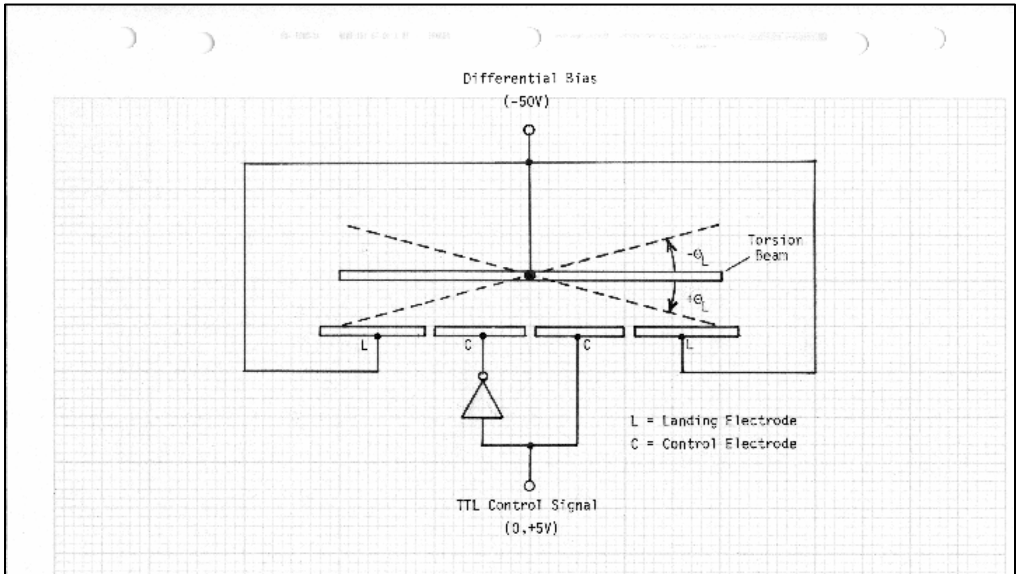
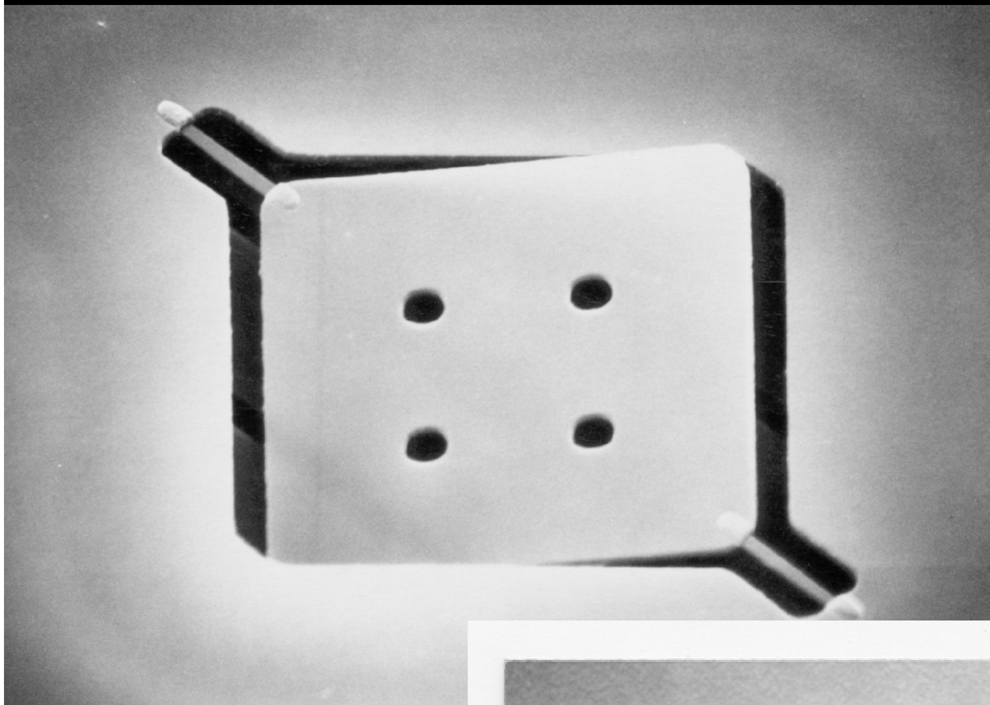


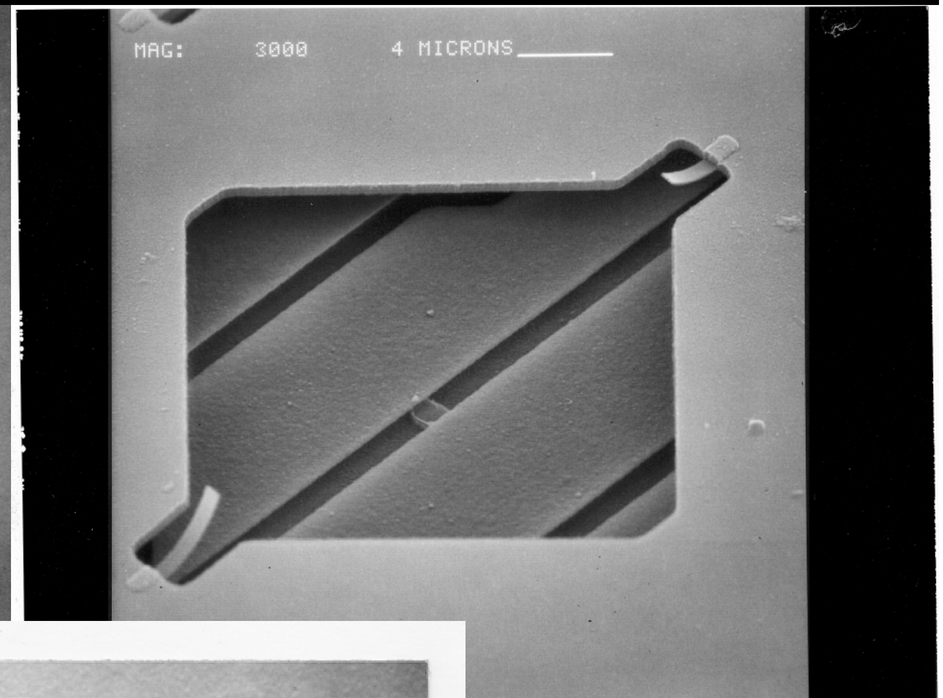
Figure 1. Bistable DMD (Cross Section)

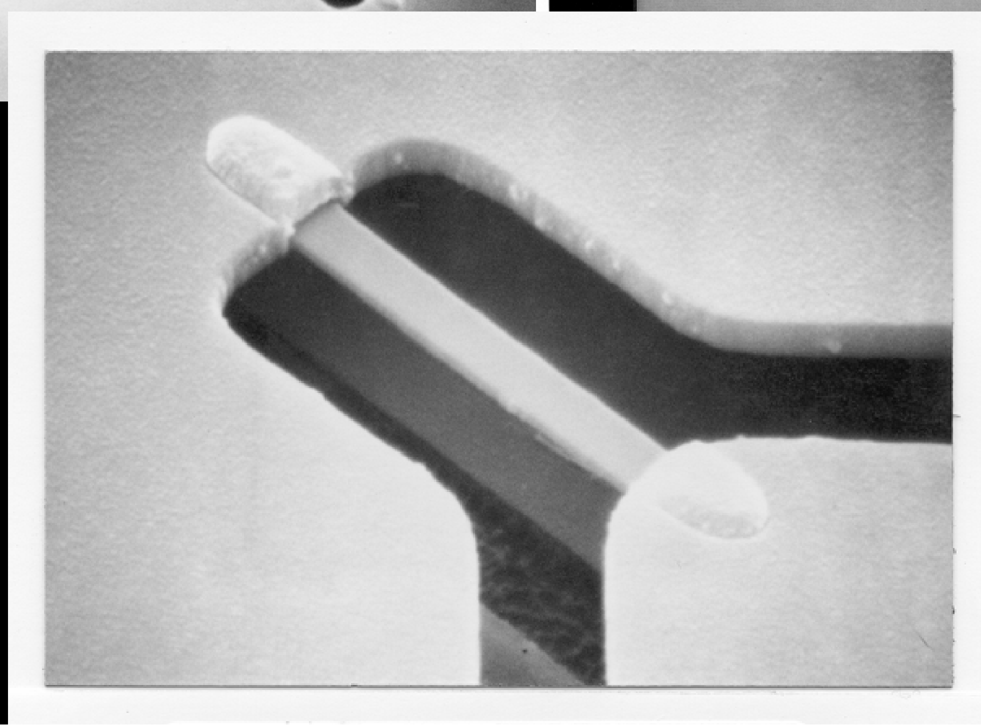
ORIGINAL CONCEPT

Bistable DMD concept as outlined by Larry Hornbeck in the first formal written description (4/22/87). This important concept later became known as the Digital Micromirror Device, and is the basis for all DMD and DLP products.

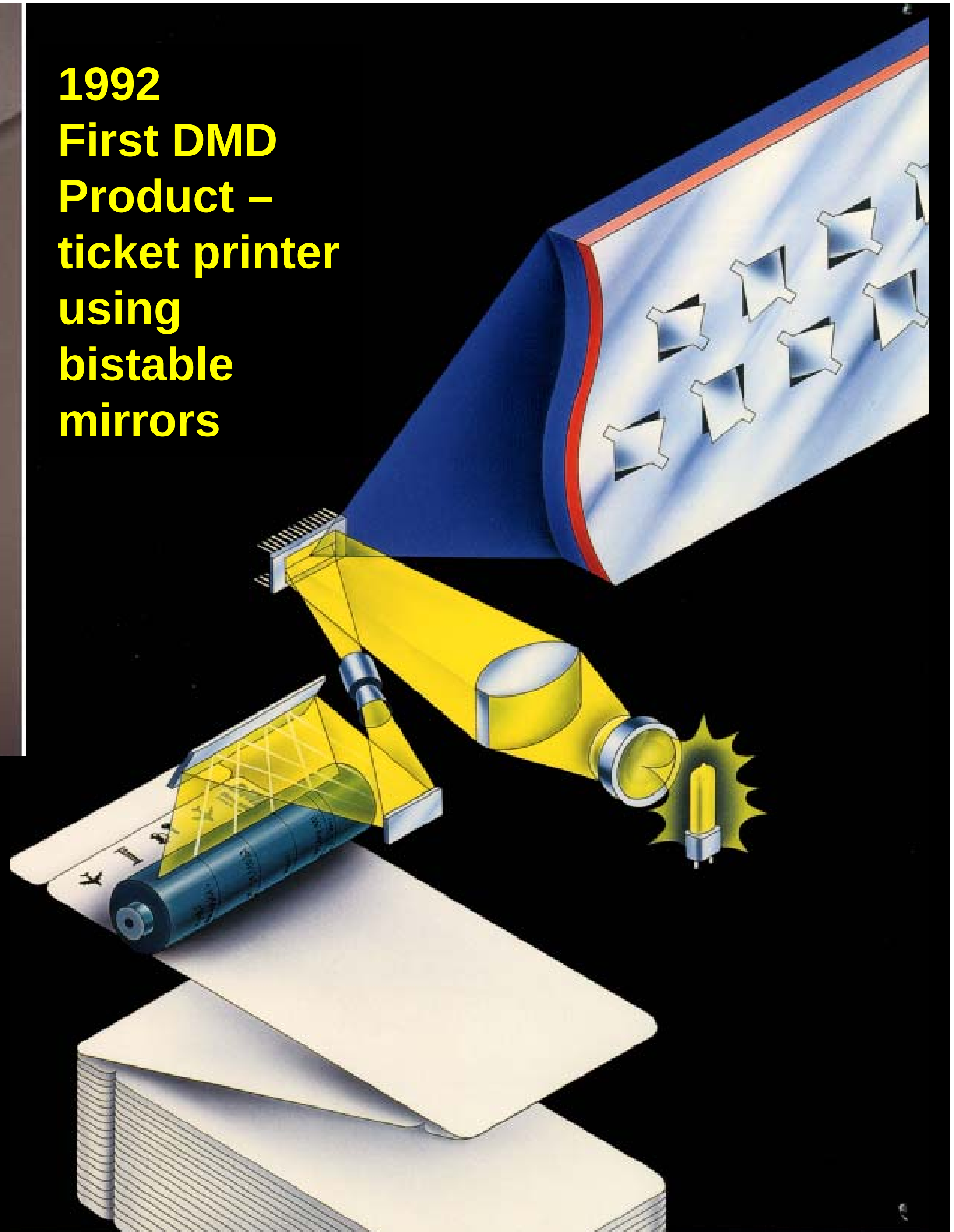
1987 Bistable DMD (basis for all future DMD devices)

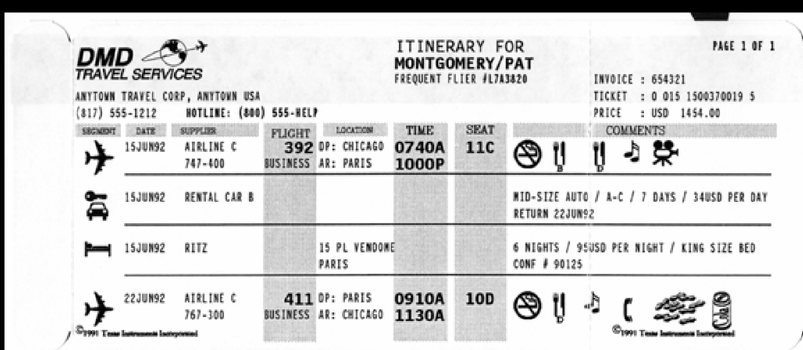






1992
First DMD Product – ticket printer using bistable mirrors





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ANYTOWN TRAVEL CORP, ANYTOWN USA
(817) 555-1212 HOTLINE: (800) 555-HELP

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MONTGOMERY/PAT
FREQUENT FLIER #L7A3820

PAGE 1 OF 1
INVOICE : 654321
TICKET : 0 015 1500370019 5
PRICE : USD 1454.00

SEGMENT	DATE	SUPPLIER	FLIGHT	LOCATION	TIME	SEAT	COMMENTS
	15JUN92	AIRLINE C 747-400	392 BUSINESS	DP: CHICAGO AR: PARIS	0740A 1000P	11C	
	15JUN92	RENTAL CAR B					MID-SIZE AUTO / A-C / 7 DAYS / 34USD PER DAY RETURN 22JUN92
	15JUN92	RITZ		15 PL VENDOME PARIS			6 NIGHTS / 95USD PER NIGHT / KING SIZE BED CONF # 90125
	22JUN92	AIRLINE C 767-300	411 BUSINESS	DP: PARIS AR: CHICAGO	0910A 1130A	10D	

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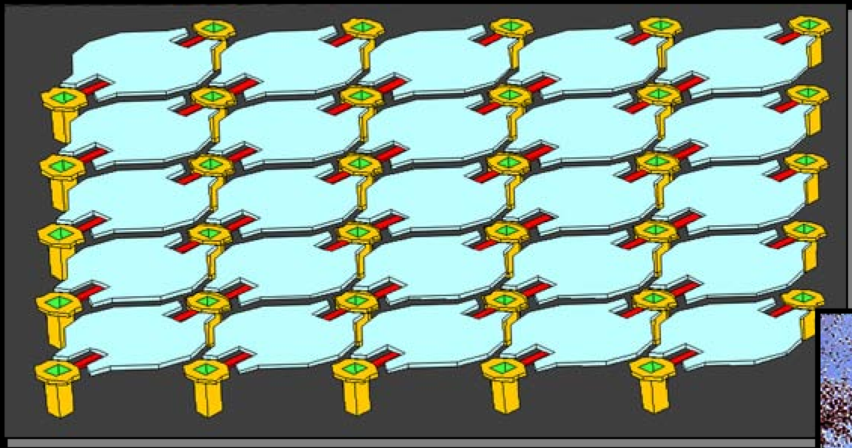
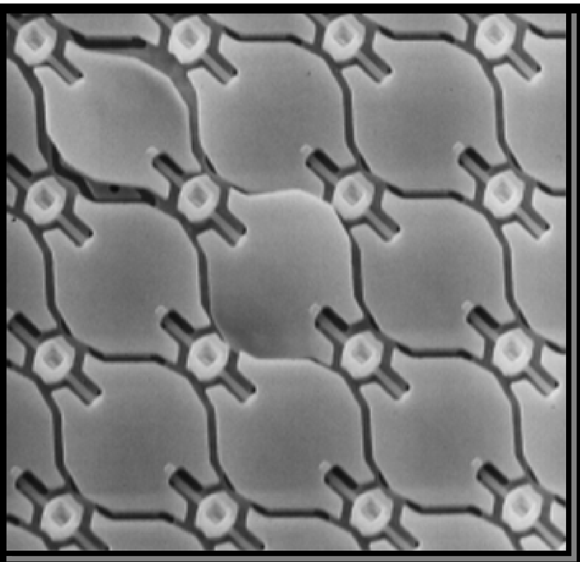
1992

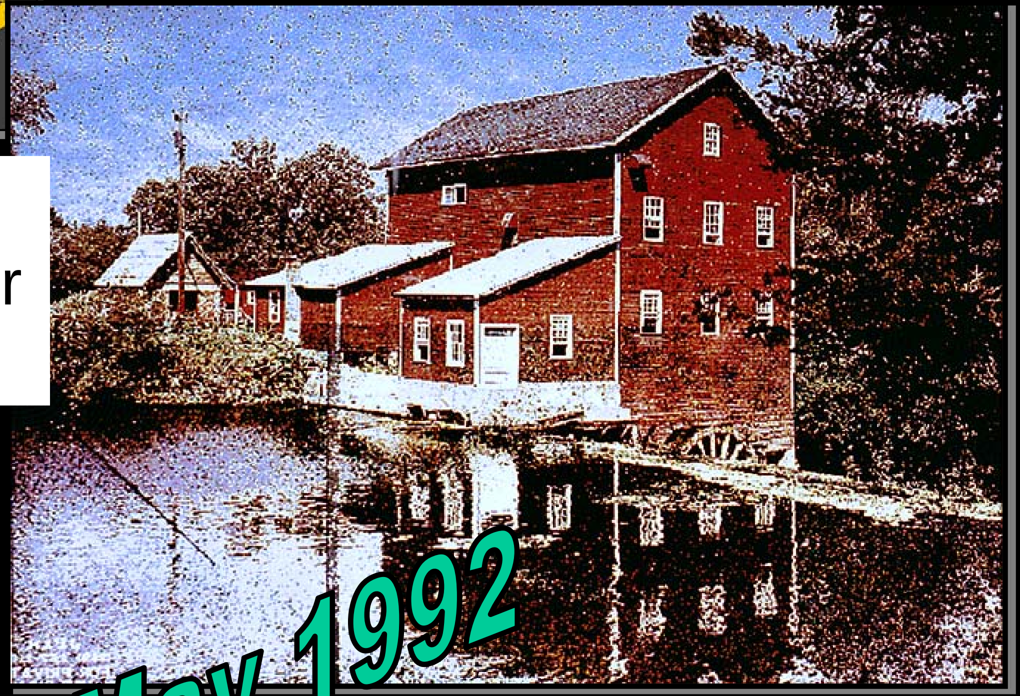
The Venture Period (1992-1996)



First Projected Full-Color Image of a "Display-on-a-Chip."

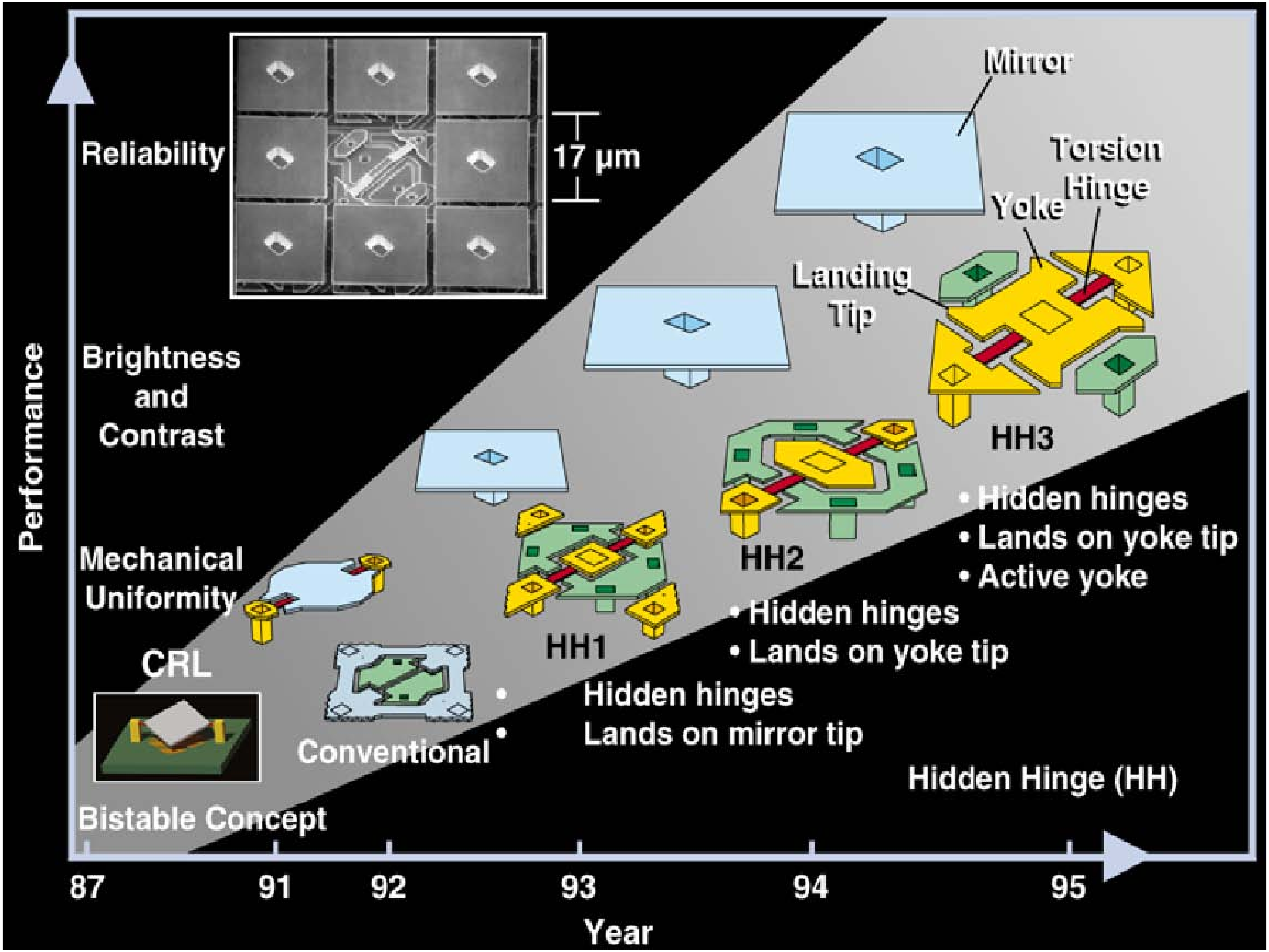
First area array pixel — the "B2" DMD Pixel, named after the stealth bomber.



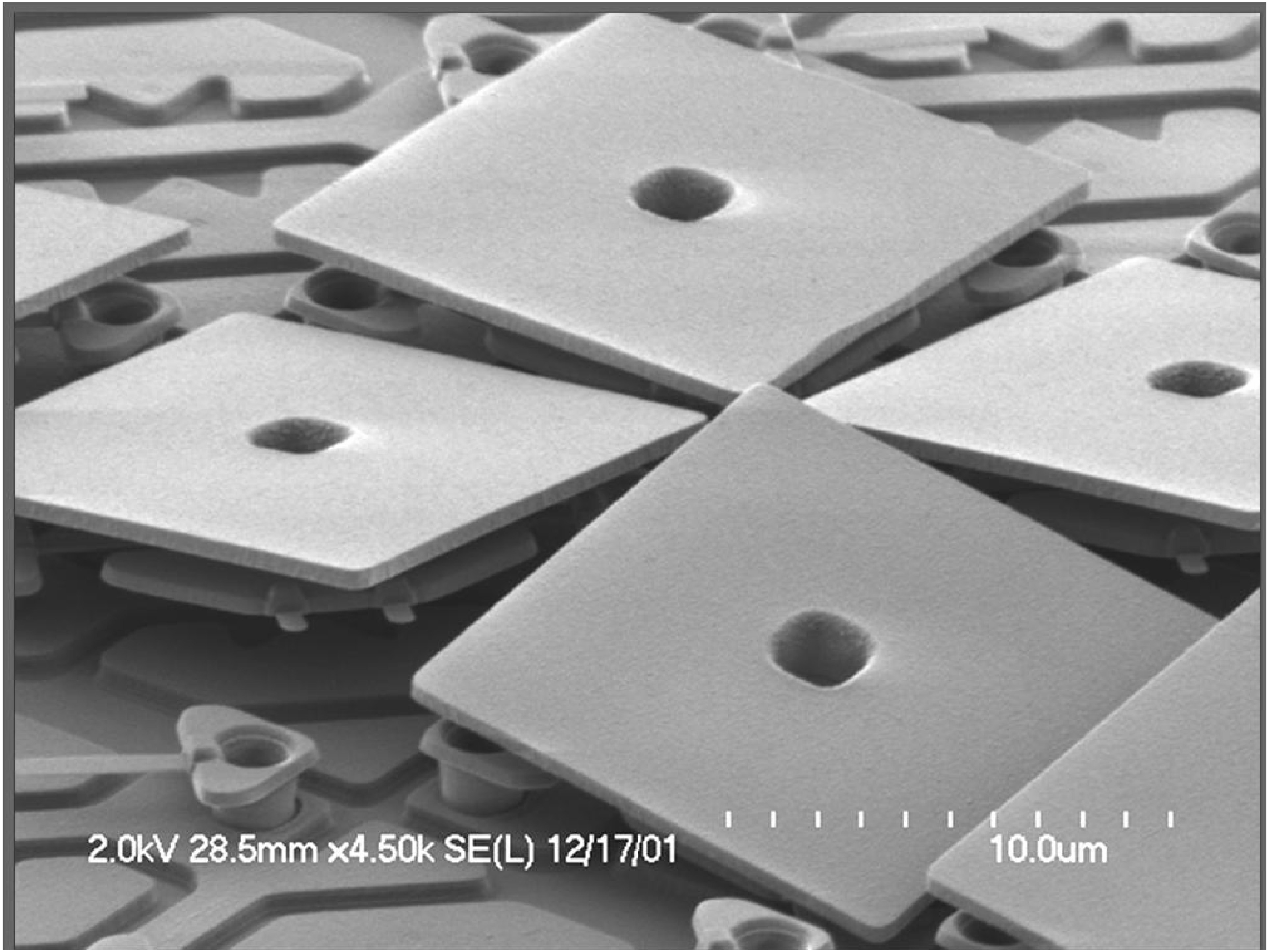


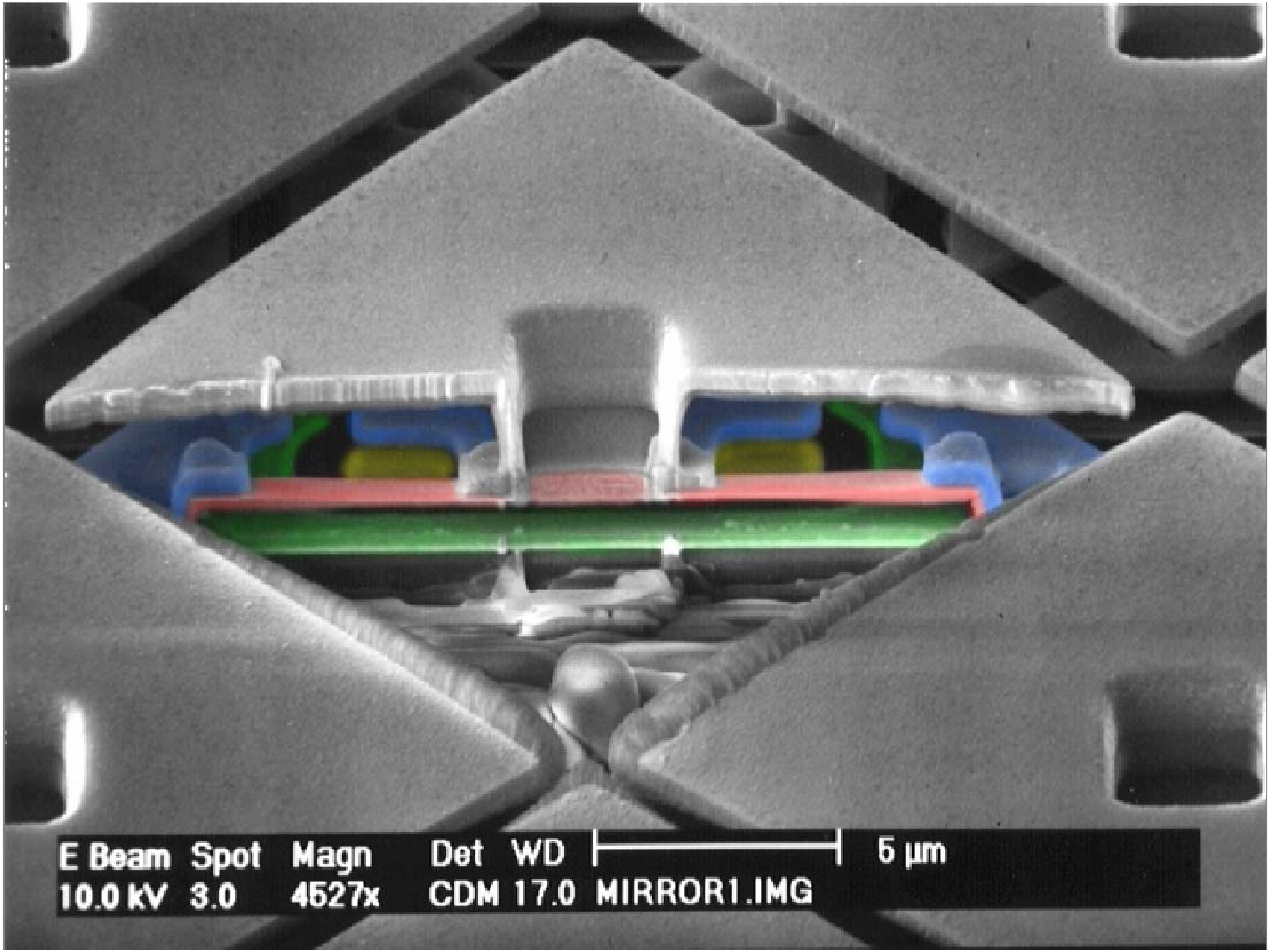
May 1992

+ 10k defects

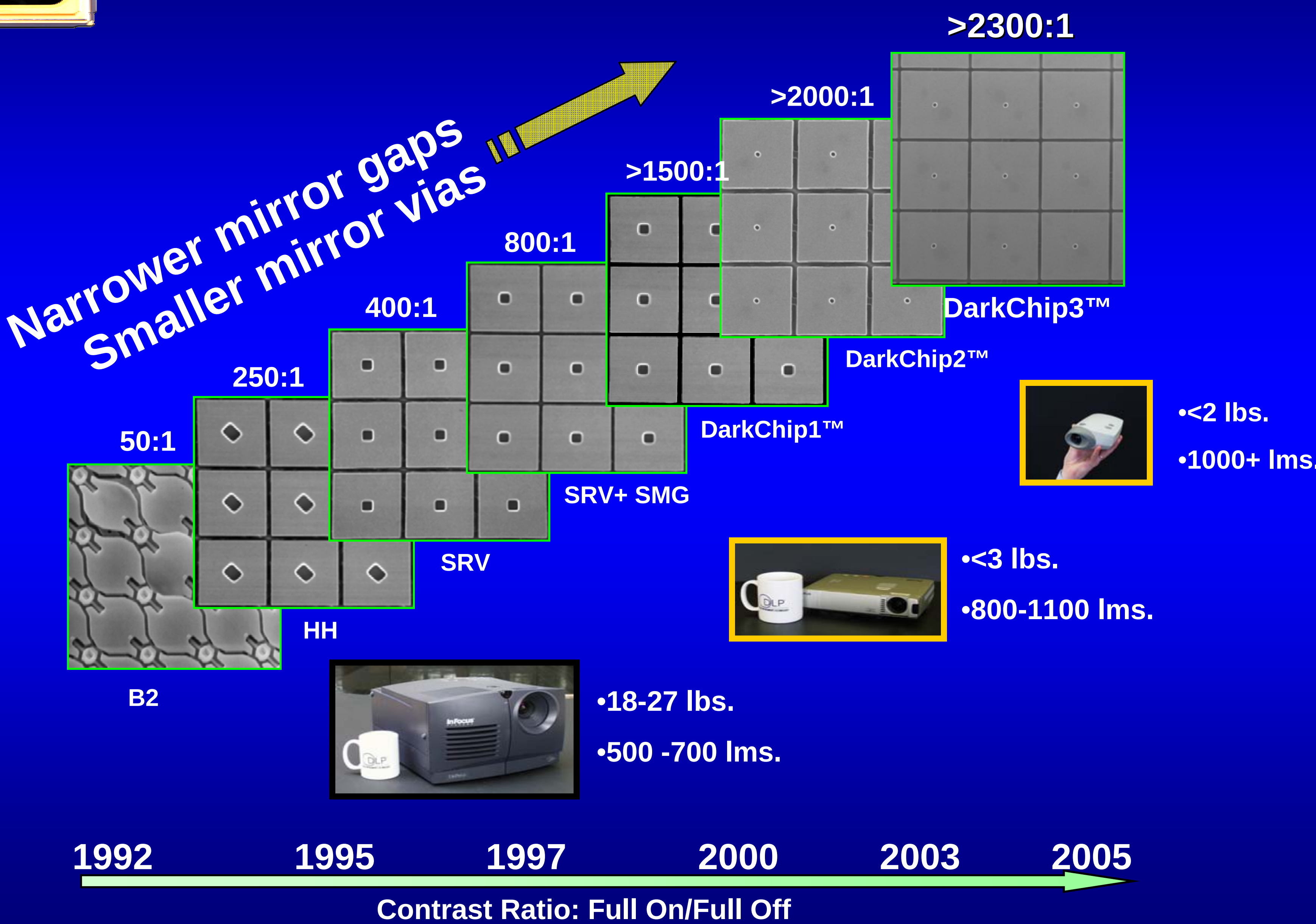


Performance
Reliability
17 µm
Brightness and Contrast
Mechanical Uniformity
CRL
Bistable Concept
Conventional
• Hidden hinges
• Lands on mirror tip
HH1
HH2
• Hidden hinges
• Lands on yoke tip
Mirror
Torsion Hinge
Yoke
Landing Tip
HH3
• Hidden hinges
• Lands on yoke tip
• Active yoke
Hidden Hinge (HH)
87
91
92
93
94
95
Year


2.0kV 28.5mm x4.50k SE(L) 12/17/01
10.0um


E Beam Spot Magn Det WD
10.0 kV 3.0 4527x CDM 17.0 MIRROR1.IMG
5 µm

Contrast Ratio Improvement



Disciplines req’d for DMD success:

Mechanical Engrs

Electrical Engrs

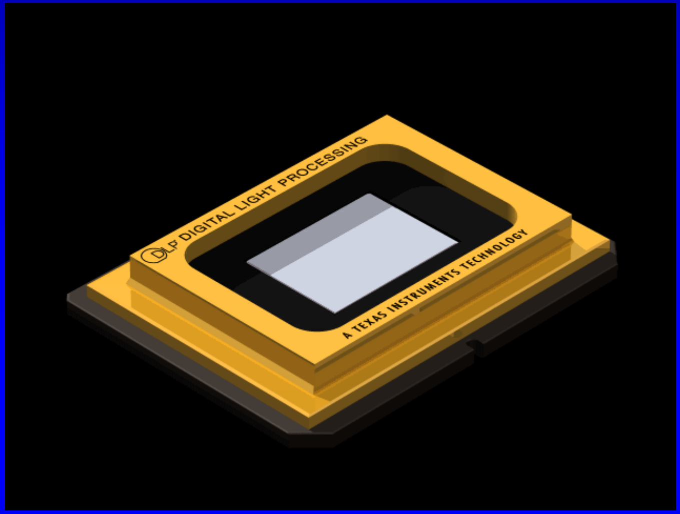
Chemical Engrs

Optical Engrs

Systems Engrs

Semiconductor Process Engrs

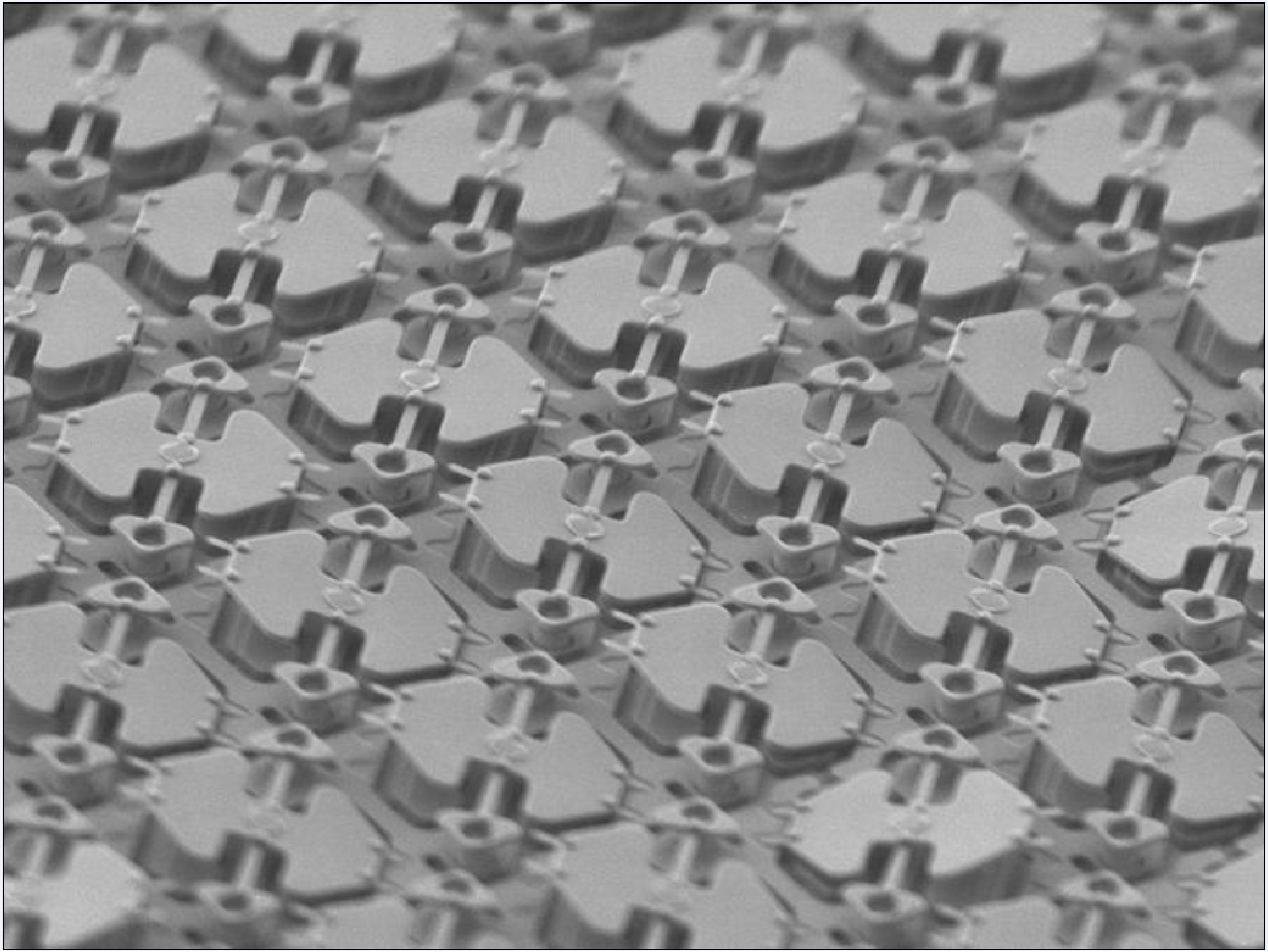
Central Research Lab Scientists



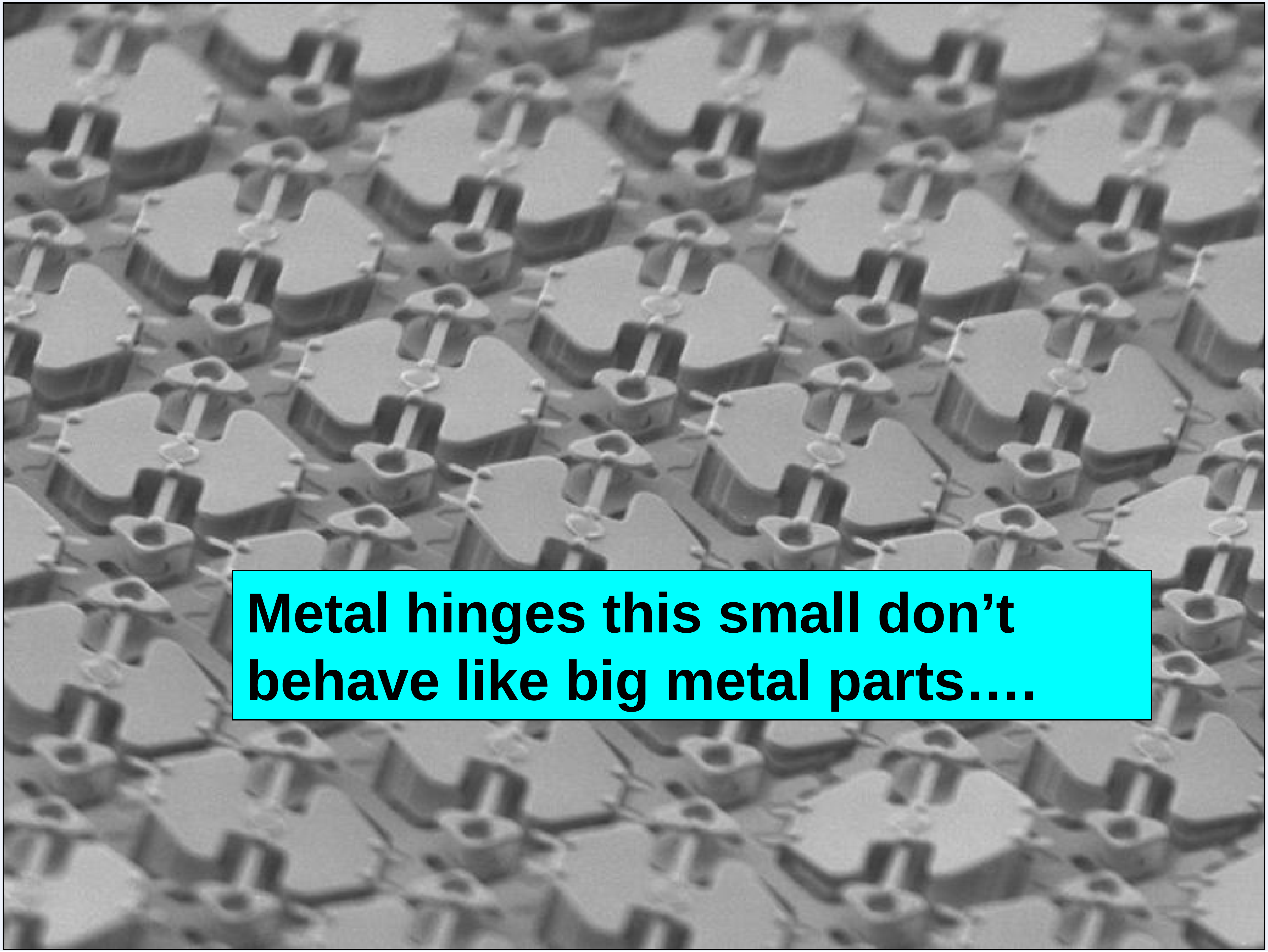
Only a few people notice that the ***weirdest technology ever invented***…… The ***dinky mirrors*** are made along with the transistors in the semiconductor manufacturing process......

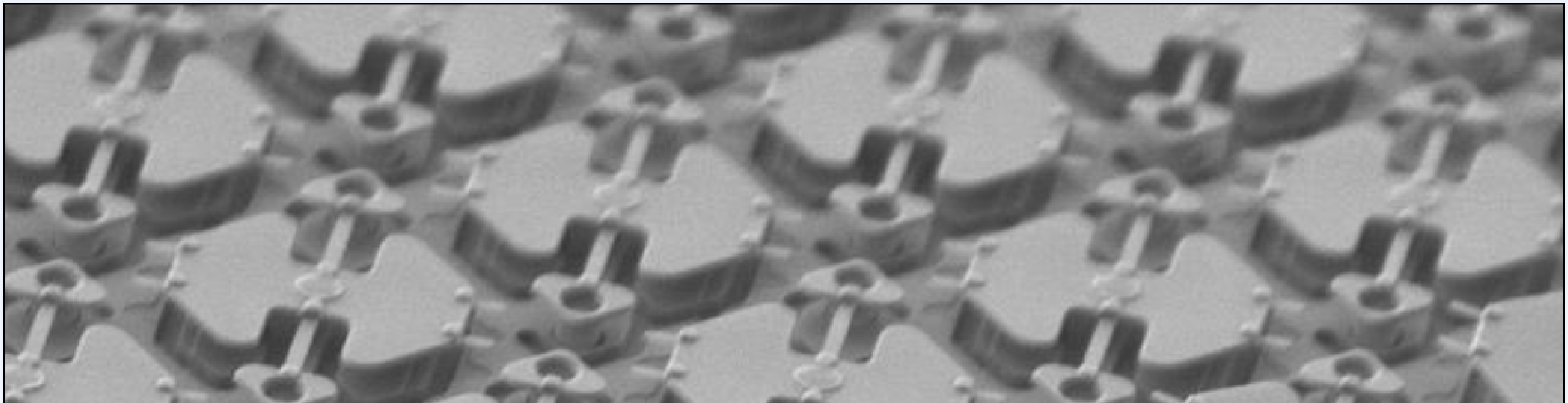
I found the whole thing so ***bizarre and weird*** that, to me, it proves that what the nutballs have been saying all along is true: The U.S.government has captured some ***bug-eyed aliens***. We're using them to ***design*** this stuff.

John C. Dvorak
PC Magazine
August 1993

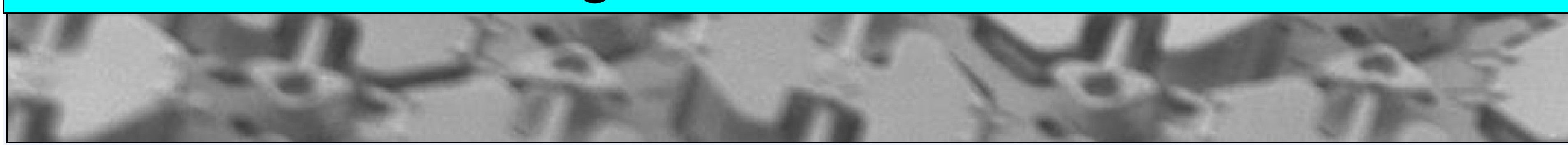


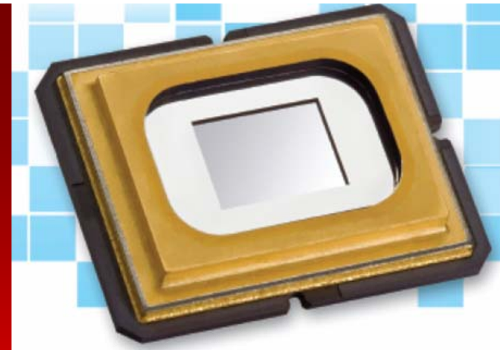
Our secret to hinge reliability…..


Metal hinges this small don't behave like big metal parts….



- **12 years continuous operation**
- **5.3×10^{12} (5.3 trillion) cycles**
- **Equivalent to 360,000 operating hours**
- **9 DMDs on test, 500K mirrors each per device, each mirror has cycled 5.3×10^{12} times, for a total of 23.9×10^{18} (quintillion) mechanical movements without a metal fatigue failure.**





HISTORIC MECHANICAL ENGINEERING LANDMARK

DIGITAL MICROMIRROR DEVICE

1996

THE DIGITAL MICROMIRROR DEVICE (DMD), REPRESENTED HERE BY ONE OF THE FIRST UNITS PRODUCED, IS A WIDELY USED OPTICAL MICROMACHINE FOR DISPLAY APPLICATIONS. THE DMD MANIPULATES LIGHT DIGITALLY THROUGH THE MECHANICAL ACTION OF UP TO TWO MILLION MOVABLE, INDIVIDUALLY CONTROLLABLE MICROMIRRORS FORMED ON A SILICON INTEGRATED-CIRCUIT CHIP. EACH MICROMIRROR MUST BE CAPABLE OF SEVERAL TRILLION CYCLES WITHOUT FAILURE.

A MULTI-DISCIPLINARY TEAM OF ENGINEERS AND SCIENTISTS AT TEXAS INSTRUMENTS INC. DEVELOPED THE DMD TECHNOLOGY FROM CONCEPTION IN 1987 TO ITS FIRST COMMERCIAL APPLICATION AS AN ELECTRONIC PROJECTION DISPLAY IN 1996. A WIDE RANGE OF VIDEO-DISPLAY APPLICATIONS USING THE DMD HAS FOLLOWED.

ASME THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS 2008