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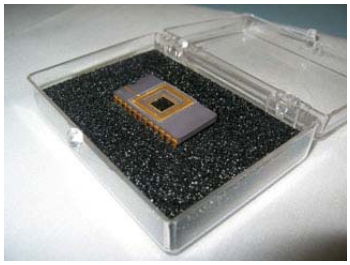

Gimbal-less Two-Axis Scanning Micromirrors

DESCRIPTION

Gimbal-less Two-Axis Scanning Micromirror Devices based on **ARI-MEMS** fabrication technology initially developed through research projects at the Adriatic Research Institute ("ARI") in Berkeley, CA, provide ultra low-power and very fast optical beam scanning in two-axes. The devices deflect laser beams to optical scanning angles of up to 30° at very high speeds, while dissipating as low as 1mW of power.

Our devices are made entirely of monolithic single-crystal silicon, resulting in excellent repeatability and reliability. Flat, smooth mirror surfaces can be coated with a thin film of metal with desired reflectivity. Larger mirrors can be bonded onto actuators for custom aperture size.

The major advantage of the proprietary gimbal-less design is the capability to scan optical beams at equally high speeds in both axes. A typical device with a 0.8 mm diameter-sized micromirror achieves angular beam scanning of up to 400 rad/s and has first resonant frequency in both axes above 2800 Hz. Large angle step response settling times of <100 μs have been demonstrated on devices with 0.6 mm diameter micromirrors. Devices can also operate in the dynamic, resonant mode, which gives significantly more angle at lower operating voltages. Resonant frequencies are in the range of several kHz.

Three types of gibmal-less two-axis actuator designs are available. The actuators lend themselves inherently to a modular design approach. Each actuator can utilize rotators of arbitrary length, arbitrarily stiff linkages, and arbitrarily positioned mechanical rotation transformers. A schematic diagram presenting the conceptual operation of the gimbal-less 2D designs is shown in Fig. 1.

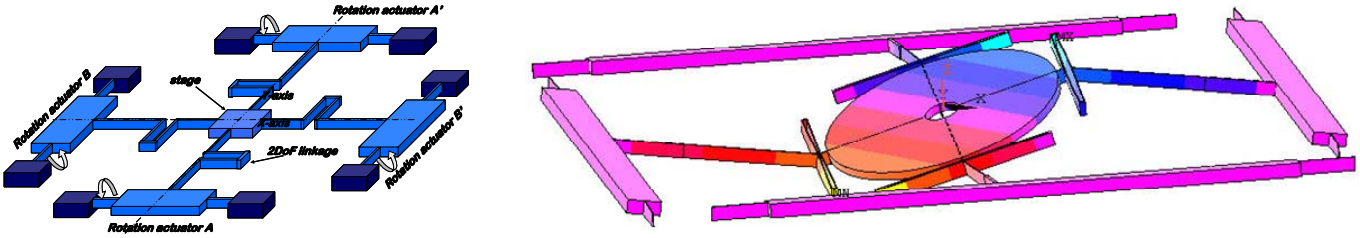

Figure 1. Schematic diagram of a gimbal-less two-axis scanning actuator based on four high aspect ratio rotators connected to the central pedestal by two degrees-of-freedom (2 DoF) linkages.

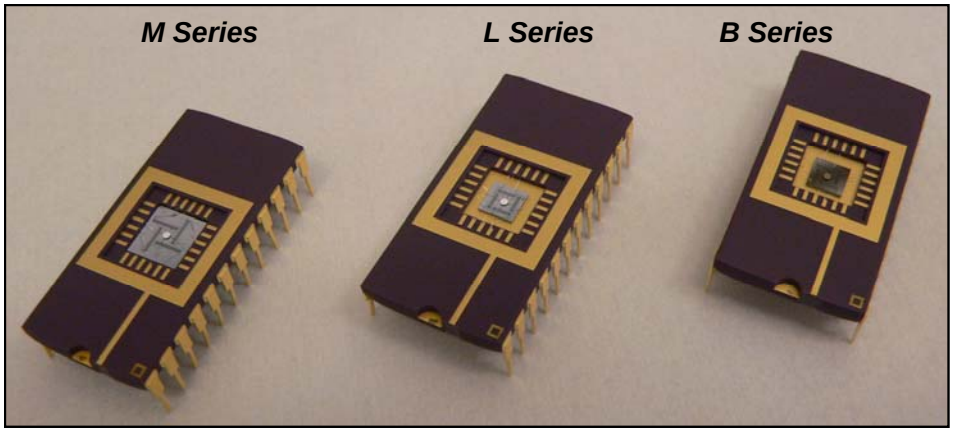

Figure 2. Photographs of the three types of actuators in 24-pin DIPs. Each actuator is combined with an ultra-thin metallized 0.8mm diameter micromirrors.

The three device types are: “B series” device, “L series” device, and “M series” device. The B series devices are designed to operate at low voltages (>8° of mechanical tilt at 100V,) exhibit the largest maximum scan angle and occupy a small die size (3mm x 3mm.) The L series devices operate at higher voltages and occupy a slightly larger die size (3.1mm x 3.1 mm.) In return, they provide higher scanning speeds. Finally, the M series devices require the highest driving voltages and occupy the largest die size (5.1mm x 5.1mm,) in order to provide the fastest scanning speeds.

STANDARD MIRRORS VS. SPECIAL SIZE MIRRORS

Standard silicon mirrors of 0.7 mm diameter are an integral part of some of our devices. Namely, they are monolithically fabricated with the gimbal-less actuator structure. Due to the limitations of the fabrication steps of the actuator, the standard mirrors are relatively thick (24 μm) devices. They have excellent flatness and polished surface, and are not normally metallized in our process.

In the past, batch fabrication of silicon devices such as two-axis micromirrors allowed for only one type/size of micromirror to be fabricated as part of the overall device. In order to produce devices with a different mirror size, most technologies require not only a new fabrication cycle, but in some cases complete actuator redesign. At ARI we provide a MEMS based, customizable aperture size beam steering technology for the first time. Namely, sets of electrostatic actuators optimized for speed, angle, area footprint or resonant driving are designed and realized in a self-aligned DRIE fabrication process. Metallized, ultra low-inertia single crystal mirrors stiffened by a backbone of thicker silicon beams are created in a separate fabrication process. The diameter, as well as geometry, of the mirror is selected by customer, in order to optimize the trade-offs between speed, beam size, and scan angle for each individual application. The mirrors are subsequently bonded to the actuators. The modular approach allows either the absolute optimization of a device prior to fabrication, or the ability to economically adapt a small set of fabricated devices for a wide range of applications. Fig. 3 below shows the relationship between mirror diameter and lowest resonant frequency for mirrors mounted in the three available types of actuators.

Special size mirrors have the clear advantage of significantly lower inertia, metallized surface, and larger size than the standard silicon mirrors. Special size mirrors of 0.8mm and 1.2mm diameter are available in any quantities. Larger sizes up to 2.4mm are available only in larger orders.

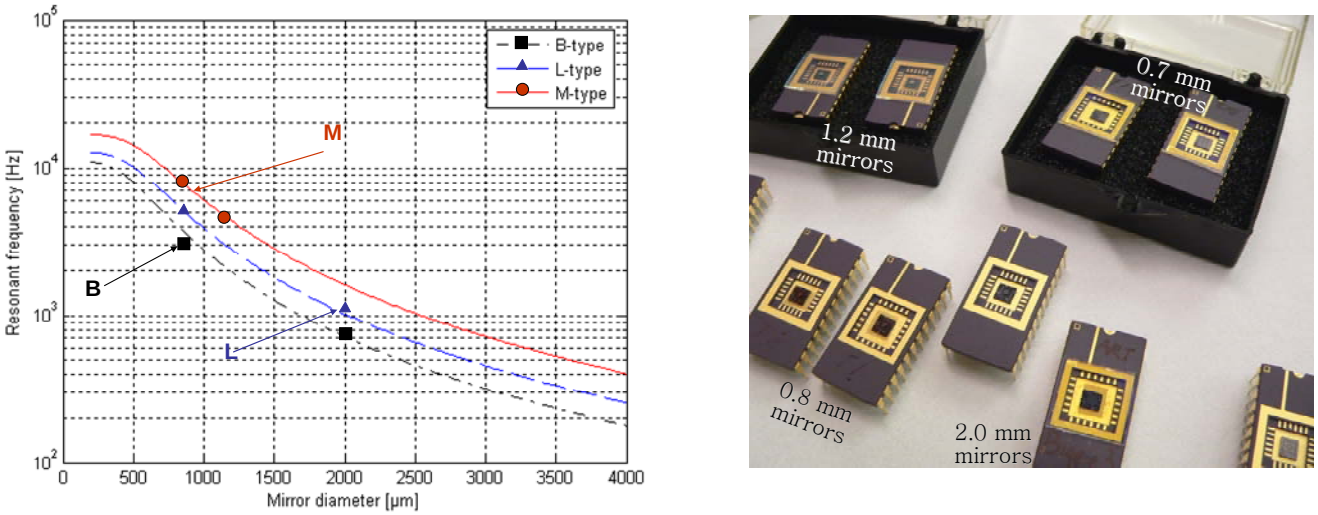

Figure 3. A plot of theoretical and measured resonant frequency as a function of bonded mirror diameter, and a photograph of devices based on B and L series actuators with 4 different types of micromirrors.