BIASED ROTATABLE COMBDRIVE ACTUATOR METHODS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of Provisional Application No. 60/191,856 filed Mar. 24, 2000, which is herein incorporated by reference for all purposes. This application is also related to commonly assigned U.S. patent application Ser. Nos. 09/809,995, 09/810,326, and 09/810,336, which were filed on the same day as this application.

FIELD OF THE INVENTION

This invention relates generally to Micro-Electro-Mechanical-Systems (MEMS). More particularly, it is related to a novel class of vertical combdrive devices serving as rotating actuators and/or position sensors and methods for operating any combdrive.

BACKGROUND ART

The advent of silicon fabrication technologies has made possible a line of integrated devices in which micro-actuators and micro-mechanical structures are fabricated using processing technology similar to that used in the integrated-circuit industry. These integrated actuators have been employed in a variety of applications, such as fiber-optic switching, optical tracking for applications such as free-space communications, inertial sensors, and magnetic disk drives. They offer small size, low cost, high reliability, and superior performance. Furthermore, micro-machined structures may be integrated with Integrated Circuits (ICs) fabricated on the same substrate.

Various actuation methods can be employed in these integrated actuators, including electrostatic, electromagnetic, thermal, and thermo-pneumatic means. Electrostatic actuation becomes particularly attractive on a small size scale, since the electrostatic force increases as the gap between two charged elements decreases. Combdrive electrodes are widely used for generating electrostatic driving forces.

It is often desirable to create out-of-plane actuation of various microstructures, such as rotation of mirrors about an axis parallel to a substrate. These rotating mirrors can be used individually or in array form for applications such as adaptive optics, visual displays, or fiber-optic switching. Vertical combdrive actuators provide rotational motion or translational motion perpendicular to a substrate. A micro-machined electrostatic vertical actuator is disclosed in U.S. Pat. No. 5,969,848, issued to Lee et al. The device of Lee et al. contains a set of vertical combdrives, with each drive capable of deflecting one edge of a square mirror. By relying on an asymmetric distribution of electrical fields when a bias voltage is applied between stationary and movable comb fingers, the device of Lee et al. allows a small vertical (i.e. out of the plane of the comb fingers) motion of each mirror edge, at most 1.5 μm.

Larger movements and more simplified fabrication techniques are provided by staggered vertical combdrives, in which the stationary and moving combdrives are positioned parallel to one another, but with the plane of the moving comb above the plane of the stationary comb. The stationary comb fingers are an integral part of the substrate, while the moving comb is fixed to the substrate only through flexures. Applying a voltage between the two comb layers causes the moving comb teeth to be attracted to the stationary teeth and move to increase the overlap area, thereby exerting a force on the moving comb. Conventional fabrication techniques for vertical combdrives using standard photolithography processes require multiple steps for patterning the comb fingers. First, one set of comb teeth is fabricated on a first wafer layer. A second wafer layer is then bonded on top of the first wafer layer, followed by patterning and etching of a second layer to form the second set of comb teeth. The two wafer layers must be aligned to a very high precision; typical applications require comb fingers of 2 μm wide with a 6 μm separation distance, so that adjacent overlapped fingers are separated by only 2 μm. Vertical combdrives fabricated using this technique are prone to alignment problems. The steppers used to align the individual die on a wafer typically have a lateral resolution of ± 0.25 μm. This resolution places a lower limit on the gap between adjacent comb fingers of about 2 μm. Because two adjacent fingers are at different potentials during operation, they cannot contact each other. At high actuation voltages, errors in alignment of the fingers can cause sideways motion and instability in the combdrive. As a result, conventional fabrication techniques typically have low production yields.

FIGS. 1A–1B depict a prior art rotating actuator employing a two-layer vertical combdrive. FIG. 1A shows rotating actuator **100** in a nominal state. A plurality of movable comb fingers **10**, extending from a first micro-machined structure **11**, are suspended above a plurality of stationary comb fingers **12**, which extend from a second micro-machined structure **13**. A rotating element **14**, attached to a flexure **15**, is mechanically engaged with first micro-machined structure **11** and therefore movable comb fingers **10**. Rotating element **14** may carry a reflective surface so as to provide a scanning mirror for a given application. It is worth noting that stationary comb fingers **12** and movable comb fingers **10** are fabricated in two different layers of a substrate (not shown in FIG. **1**A). FIG. **1**B depicts a rotating state of rotating actuator **100** of FIG. **1**A. The rotation can be generated by an electrostatic means, e.g., by applying a voltage between stationary comb fingers **12** and movable comb fingers **10**. The capacitance between movable comb fingers **10** and stationary comb fingers **12** may be measured and resolved to determine and control the angular position of movable comb fingers **10**.

In a combdrive actuator, it is desirable for the angular position of the movable comb fingers to vary with the applied voltage in a linear fashion; and it is also desirable for the stationary comb fingers and movable comb fingers to be aligned with respect to each other in a precise lateral alignment. This is owing to the fact that if the stationary and movable comb fingers are not well aligned, such that each of the movable comb fingers is centered within the gap between its respective neighboring stationary fingers, there arises a net lateral force upon application of a voltage between the stationary and movable comb fingers. Such a lateral force can cause non-linear and unstable behaviors in the motion of movable comb fingers. For example, sufficient lateral force can cause the movable comb fingers to snap into contact with the stationary comb fingers.

In the prior art combdrive system of FIGS. 1A–1B, however, because stationary comb fingers **12** and movable comb fingers **10** are not coplanar and therefore not substantially engaged in their initial positions, the motion of the combdrive thus constructed is significantly nonlinear, unless a sufficient force is exerted on the combdrive to engage stationary comb fingers **12** and movable comb fingers **10**. Moreover, precise lateral alignment between stationary comb fingers **12** and movable comb fingers **10** is also