Figure 12: (a) Schematic diagram of the assembly process; (b) SEM micrograph of an assembled array of 3-D microstructures.
Figure 11: Hysteresis behavior of a Type-I actuator under forward and reverse biasing.

Figure 10: Angular and vertical displacement of the structure plate with respect to the biasing magnetic field intensity $H$. (a) Theoretical and experimental rotation angle $\theta$. (b) Vertical displacement $y_{\text{max}}$. The size of the plate is $1 \times 1 \text{mm}^2$, the beam length and width are $400$ and $100 \mu \text{m}$, respectively. The beam thickness is $1 \mu\text{m}$.

Figure 12: Hysteresis behavior of a Type-I actuator under forward and reverse biasing conditions. Theoretical curve for $H=0$ and experimental curve for $H=0$.
Figure 9: Sequential video images of a Type-1 magnetic actuator (a) before applying the magnetic field; (b) when $H_{ext} = 3.34 \times 10^4 A/m$; (c) at the maximum displacement.
Figure 8: Video-microscopy inspection setup.
perimeter of PSG mesa

Permalloy plate

cantilever beams

Figure 6: SEM micrograph of (a) top view and (b) perspective view of a Type-1 actuator.

Figure 7: Calibrated B-H loop (in both easy and hard axes) of the Permalloy thin film.
Figure 5: Major fabrication steps of a Type-1 actuator.
Figure 3: Schematic illustration of the mechanism of Type-1 magnetic actuator biased using an external electromagnet. (a) Rest position of the actuator when $H_{ext} = 0$; (b) out-of-plane actuation when $H_{ext} \neq 0$ is provided by an external electromagnet; $F_1$ and $F_2$ are the induced magnetic forces on the upper and lower edges of the plate; (c) a simplified force system (containing $M_{mag}$ and $F$) acting at the free-ends of the cantilever beams.

Figure 4: Schematic diagram of a flexure cantilever beam under the magnetic torque $M_{mag}$. 
Figure 1: Schematic diagram of surface-micromachined magnetic actuators (a) with cantilever-beam supports (Type-1 actuator); (b) with torsion beam supports (Type-2 actuator), (c) with a plain hinge support or (d) a hinge support in conjunction with cantilever-spring loading (Type-3 actuators).

Table 1: Measured properties of Permalloy magnetic thin-film.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation magnetization $M_s$</td>
<td>1 - 1.5 Tesla</td>
</tr>
<tr>
<td>Coercive force $H_C$</td>
<td>0.6 Oe (47 A/m)</td>
</tr>
<tr>
<td>Relative permeability $\mu_r$</td>
<td>4500</td>
</tr>
</tbody>
</table>

Figure 2: Schematic of a Type-1 Permalloy magnetic actuator with two cantilever-beam supports. (a) Top view and (b) side view.
List of Tables

List of Figures