pressure of the fingers reading the display). After the displayed image has been read, pins **21** may be reset by forcing them back against the force of pressure-based device **51**.

Another, preferred, approach to pin retention is a two-stage pin retention system. As the pins are set, a temporary pin retention mechanism holds the pins firmly enough to keep them in the position where they were set, but not firmly enough for reading by the user. After the pins have been set to the desired configuration, a locking mechanism holds the array of pins firmly in place, permitting reading by the user. When the time comes to reset the display, the pins are first unlocked to allow free movement. (The temporary pin retention mechanism may also be released during reset, depending upon implementation, but this may not be necessary because of the relatively low forces required to move the pins against the force of the temporary pin retention mechanism).

Two-stage pin retention mechanisms, while more complex than the single-stage approach described above, have the following advantages: 1) less force is required to set the individual pins, 2) the pins can be held firmly while the user is reading the display, 3) less energy is required to operate the display, 4) less force is required to reset the pins (which is important when there are a large number of pins to reset in a short period of time), and 5) wear of the pins and locking mechanisms is reduced.

As part of the two-stage pin retention mechanism, the purpose of temporary pin retention is to hold the pins that have been set and the pins that have not been set in their correct respective positions during the process in which the selected pins are set. The temporary mechanism thus holds the pins against the influences of gravity, electrostatic attraction, light incidental contact, and acceleration (jarring or shaking) to which the display may reasonably be expected to be subjected. At the same time, it is desirable that this mechanism not require unduly high force for setting or resetting the pins, and that it have little tendency to wear or to cause wear in the pins or other display components. The mechanism may be configured to release entirely during display reset, though this capability may add unwanted complexity to the display design.

One example **55** of a temporary pin retention mechanism is shown in FIG. **8** (with the pin heads cut away), and includes flexible sheet **56** (and would also comprise a layer **43** in a stacked array). A sheet of material that is strong and flexible but with low elasticity (e.g. MYLAR) is included as a component of the matrix that holds pins **21**, positioned so that a feature on each pin **21** (for example head **31** or a ridge **33** on shaft **27**) forces part (at openings **58**) of flexible sheet **56** to bend or stretch slightly to allow passage of the feature whenever a pin **21** is set or reset. Openings **58** in flexible sheet **56** through which the pins pass may be holes only slightly larger than pin shaft **27** (so that the passage through the hole of any portion of the pin with larger diameter causes the flexible sheet to stretch), or openings **58** may include cuts **60** thereat in flexible sheet **56** radial to the surface of an opening **58**, effectively forming tabs of the material of flexible sheet **56** that flex to allow passage of larger-diameter portions of pins **21**. In either event, a pin that is set or reset pops through the flexible sheet, and is held in place by the force that would be required to pop it back. When used in a multi-level display (accommodating setting of multiple pin heights), it is expected that either a separate sheets **56** in a layer **43**/**55** or multiple pin structures at each pin **21** (e.g. ridges **33**) will be required for each set level.

Alternatively, compressible (springy) material could be utilized for temporary pin retention. An example of this would be a thin foam plastic sheet of foam with very fine cell structure or the like. A sheet of this material can be included in a layer **43** of the matrix of layers holding the pins, and positioned so that the material contacts either the smooth shafts of the pins or a textured surface on the pins. Pin retention is accomplished by means of friction between the pins and the sheet of material. With the use of a sufficiently thin sheet of material, tendency of the pins to spring back after being set or reset can be minimized. This approach would be useful in multi-level displays, since one sheet of material can be configured to support multiple pin displacements.

A third approach to temporary pin retention would utilize high viscosity liquid or plastic material. The pins and a corresponding layer **43** in the pin holding matrix are made to contact a material (e.g. petroleum-based grease or silicone) that allows setting and resetting motion of the pins, but holds them lightly due to the viscosity of the material. Such an approach requires means to prevent the flow of the material to portions of the display where it is not wanted (e.g. embedding it in a fabric), and prevention of contamination of the material by abrasives (which could cause wear) or other substances (by limiting access to the environment and by selection of material for resistance to contamination).

An approach to temporary pin retention utilizes flexible clips **65** in a thin sheet array **67** of high strength material mounted in the pin holding matrix of layers in a way that permits a small degree of lateral movement (two different embodiments of which are shown in FIGS. **9**A and **9**B). This approach also may be utilized for pin locking during reading. A controlling mechanism (manual or automatic) sets array **67** in one of several positions depending on the function being performed by the display. An example would be a three-position locking mechanism. The sheet has holes **69** to allow the motion of the pins each defining a spring-like or clip-like structure **65** made out of the material of array **67** and associated with each of the holes **69**. The clips engage features (heads, ridges, or grooves) on pins **21**.

For the three-position design, sheet array **67** is positioned in an intermediate position during the pin setting process, so that clips **65** lightly engage pins **21**, and the pins that are set move frictionally past the clip arms **71** and are held temporarily thereby. After the pin setting process is completed, sheet array **67** is shifted laterally to a second position where the clips firmly hold the pins in place (i.e., the pins are locked in position) to resist finger pressure as the user reads the display. During reset of the display, the sheet may be shifted back to the intermediate position to lightly engage the pins, or to a third position where the clips are completely disengaged from the pins (the third position can be used if the display is always positioned so that gravity will hold the pins in the reset position until the writing process begins). Flexible clips offer the benefit of providing two functions (temporary retention and locking) in one layer of the display though two layers may still be desired (as shown in FIG. **13**).

Pin locking is based on the application of a small amount of force (from a source other than the actuators that set the pins) to engage a mechanical interlock that holds the pins firmly in place and resists finger pressure while the user reads the display (such as clips **65** discussed above). Because of the close spacing of the pins and consequent small dimensions of the pin features, the actual travel distance of the interlock mechanism may be very small—less than the distance between pins. Mechanical stability can be provided by configuring the interlock mechanisms for all the pins onto a single sheet, which is incorporated in the stack that forms the pin matrix, and