Technology Review:

Air Delivery Systems Utilizing Piezofan or Standard Fans

Qpedia continues its review of technologies developed for electronics cooling applications. We are presenting selected patents that were awarded to developers around the world to address cooling challenges. After reading the series, you will be more aware of both the historic developments and the latest breakthroughs in both product design and applications.

We are specifically focusing on patented technologies to show the breadth of development in thermal management product sectors. Please note that there are many patents within these areas. Limited by article space, we are presenting a small number to offer a representation of the entire field. You are encouraged to do your own patent investigation. Further, if you have been awarded a patent and would like to have it included in these reviews, please send us your patent number or patent application.

In this issue our spotlight is on air delivery systems using Piezofan or standard fans. There is much discussion about its deployment in the electronics industry, and these patents show some of the salient features that are the focus of different inventors.

Low-Profile Axial-Flow Single-Blade Piezoelectric Fan ,
US5861703 A, Losinski, Armand

This fan offers the primary advantages of a self-ducting axial air flow design in a low profile package.

Fan 300 contains a substantially hollow and longitudinally extending housing 302 having a proximal end 304 and a distal end 306. The housing 302 includes a base 308, a top blocking cover 310 and a pair of low-profile side walls 312, 312' between the base 308 and the top blocking cover 310. An air input region at the proximal end 304 of the housing 302 and an air output region at the distal end 306 of the housing 302 provide an axial flow of air extending from the air input region to the air output region.

Fan 300 also contains a single fan blade 314 positioned inside the housing 302 and attached to the housing near the air input region by a plurality of vertical mounting posts 316. These mounting posts 316 have a narrow profile to promote the flow of air between the mounting posts 316 from

PATENT NUMBER	TITLE	INVENTORS	DATE OF AWARD
US5861703 A	LOW-PROFILE AXIAL-FLOW SINGLE-BLADE PIEZOELECTRIC FAN	Losinski, Armand	May 30, 1997
US 6,579,064 B2	BLADE FOR A COOLING FAN	Hsieh, H., et al.	June 17, 2003
US 8,322,889 B2	PIEZOFAN AND HEAT SINK SYSTEM FOR ENHANCED HEAT TRANSFER	Petroski, James	Dec. 4, 2012

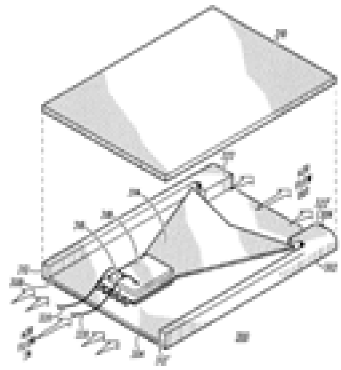
the air input region to the air output region. In one embodiment, the single fan blade 314 comprises a graphite-composite material having a high stiffness-to-mass ratio. The single fan blade 314 may also be tapered depending upon design considerations.

Fan 300 also contains a piezoelectric element 318 fixedly mounted to the single fan blade 314. This may be accomplished with an adhesive material or any other viable mounting technique. The piezoelectric element 318 comprises at least one sheet of piezoelectric ceramic material. When more than one sheet of ceramic is used, the sheets are laminated together under pressure and temperature. The laminated sheets are substantially covered on all external surfaces with a conductive metallization coating. A pair of lead wires 320 are then attached to piezoelectric element 318. In one embodiment, lead wires 320 are connected to a drive circuit which activates the piezoelectric element with an alternating current.

A pair of end blocks 322, 322' are located in the air output region between the sidewalls 312, 312' and a non-attached end of the single fan blade 314. The pair of end blocks 322, 322' help to control the flow of air through the housing 302. Air flow in occurs at the proximal end 304 of the housing and air flow out occurs at the distal end 306 of the housing 302.

It should be understood that the only necessary components for the piezoelectric fan assembly are a housing defining an axial flow-through internal cavity, a single fan blade positioned inside the housing and attached at only one end to the housing, a piezoelectric element fixedly mounted to the single fan blade, and a means to activate the piezoelectric element. In a preferred embodiment, the means to activate the piezoelectric element will be a drive circuit.

One specific custom application which would be ideal for a low-profile single-blade piezoelectric fan would be a laptop computer. As a trend in the industry is toward smaller laptop computers which offer higher performance, it becomes difficult to



cool the components, processors and circuitry associated with these increasingly complex machines. Localized areas of the laptop computer circuit boards that control advanced graphics and similar systems are known to generate large amounts of heat that must be dissipated to assure reliable operation of the computer. A dual-blade piezoelectric fan design may not be acceptable for this application because of its high profile and lack of axial air flow.

The pair of end blocks 322, 322' along with the fan blade 314 cause the air to change its path so that it travels around the end blocks 322, 322'.

Inside the housing, the mounting posts 316, the single fan blade 314, the piezoelectric element 318 as well as the lead wires 320 are also provided. Note that in a preferred embodiment, the housing will be designed such that the single fan blade approaches but never actually touches the base 308 or the top blocking cover 310.

In still another embodiment of the present invention, the housing- may contain blade stop blocks for high-gravity applications which require a controlled peak deflection. Blade stop blocks merely set the travel limits for the blades inside the housing. Blade stop blocks may also provide a support for the blade to eliminate high ceramic tensile stress in high shock environments. The importance of an axial airflow in the present invention cannot be understated. Axial airflow is important because it eliminates the need for additional ducting to feed blade corner inlets. This allows for higher density packing. Stated another way, the volume of space required to facilitate the air inlet in a piezoelectric fan having an axial flow is substantially less than the volume of space required for a piezoelectric fan having a conventional air flow design. Thus, the amount of real estate in an electronic enclosure dedicated to an axial flow piezoelectric fan is substantially less than a conventional flow piezoelectric fan.

Axial flow is advantageous for applications involving a substantially flat circuit board or electronic component system in a housing assembly that provides little clearance for airflow. In such an environment, a strong axial flow of air generated by a piezoelectric fan may prove capable of venting localized thermal regions on the board and provide efficient transfer of air throughout the entire electronic cabinet. As electronic products are being designed using smaller and lighter components, a low-profile cooling system, in the form of a single-blade piezoelectric fan may meet strict height requirements and be easily integrated into low-profile electronic products. Whereas rotary fans may be made as small as about 20 mm high, a single-blade piezoelectric fan of similar capabilities may be merely about 5 mm high or less.

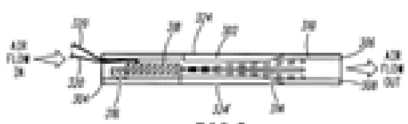


FIG.5

Traditional vibrating fan designs do not create axial flow. In the present invention, a strong axial flow is an important feature of the fan blade and housing design and these components are designed so as to maximize the axial flow across the piezoelectric fan.

In order to achieve the desired axial air flow, the shape of the housing is an important design consideration. The housing design will be made in

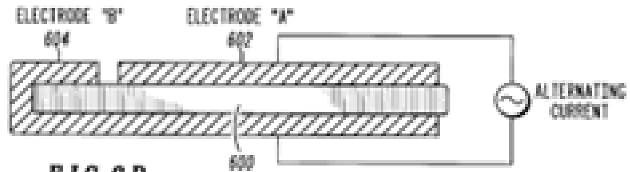


FIG.6B
SIDE VIEW

conjunction with the fan blade design in order to achieve the desired airflow characteristics. In one embodiment of the present invention, the housing may be directly integrated into an external casing of a laptop computer, for example. In another embodiment of the present invention, the housing may be created from a base, a top blocking cover, and a pair of low-profile sidewalls there between.

One major advantage with using a single-blade, as opposed to a dual-blade design, is that the profile of the fan will be only one-half as high. In simple terms, a single-blade fan is only half as high as a dual-blade fan and uses only half as much material. This allows a single-blade fan to be integrated into products and applications where a dual-blade fan in not feasible. One challenge involved in the design of a single-blade piezoelectric fan is that there may be additional vibration as compared with a dual-blade design.

The effects of vibration may be minimized in two ways. The present invention employs both of the techniques described below to minimize vibration. First, by minimizing the moving mass one can significantly reduce the vibration generated. Utilizing high stiffness blade materials allows for thinner, reduced weight blades which still maintain the desired resonant frequency. Moreover, the mass of the ceramic wafer, which forms the piezoelectric element, may be reduced by using a high purity ceramic material which may be sliced into thinner wafer elements which are then attached to the fan blades.

Another method of reducing vibration employed by the present invention involves decoupling the fan mass from the electronic enclosure. This has the effect of reducing the transfer of vibration to the end user. Thus, a mono-blade (also called a single-blade) fan design in which vibration effects have been reduced may be used for many new applications.

In general, the frequency of the oscillation of the fan blade depends upon the magnitude of the input voltage and also upon the length and stiffness of the fan blade. Depending upon design variables, the blades may be driven at any suitable speed such as a frequency from about 20 to about 1000 hertz. The driving frequency is approximately equal to the natural resonant frequency (fundamental frequency) of the blades to optimize fan efficiency.

The relationship between the fan blade design and the means to activate the piezoelectric element (typically a drive circuit) is another important design consideration. In a preferred embodiment, an alternating input voltage will be introduced at a resonant frequency which is tuned to the fan blade design such that a maximum sweep height for the blade can be achieved. Thus, the driving voltage will be one mechanism by which the fan blade displacement may be controlled. In a preferred embodiment, the fan blade will be driven at its own resonant frequency for maximum efficiency.

The piezoelectric fan blade material will be dependent upon the specific environment in which the fan will operate, however, as a general rule, the fan blade will be made from a material having a high stiffness-to-weight ratio and a low mass. A graphite-epoxy material, for example, meets these requirements, and also exhibits anisotropic properties that can render it stiffer in one axis relative to another. Other suitable blade materials include, but are not limited to, steel, aluminum, Mylar, or fiberglass. Of course, a lightweight fan may provide reduced vibration and require less power consumption.

Blade For a Cooling Fan,
US 6,579,064 B2 Hsieh, H., et al.

A lateral-blowing fan in accordance with the present invention is composed of a housing (10), a stator (20), a rotor (30) and a cover (40).

The housing (10) has a bottom plate (11) and a plurality of arcuate notches (14) is defined through the bottom plate (11). External air can flow in the housing (10) through the notches (14). Three contiguous side walls (12) are formed on the bottom plate (11) to define a circular chamber (13) in the housing (10) and an outlet (131) is defined between an opposed two of the side walls (12).The stator (20) is received in the chamber (13) and has a circuit board (21) formed at a bottom thereof. The circuit board (21) is mounted on the bottom plate (11). The notches (14) are located outside the stator (20) and not covered by the circuit board (21).

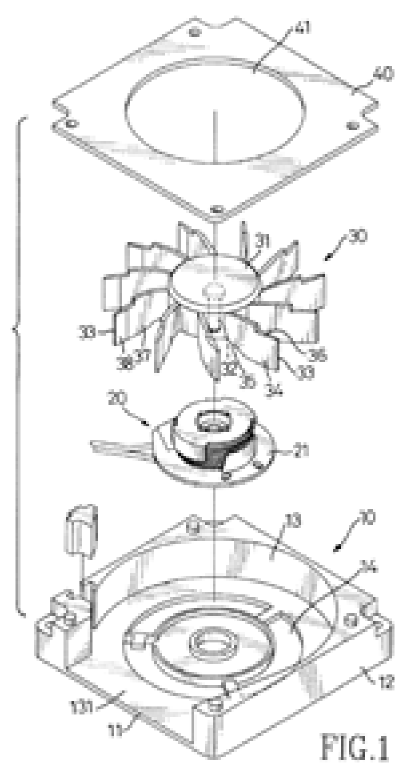


FIG.1

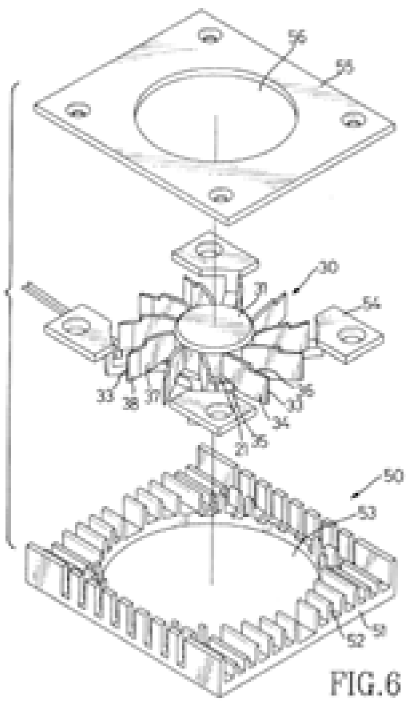


FIG.6

The rotor (30) is also received in the chamber (13) and has a hollow body (31) covering the stator (20). A spindle (32) is formed at the center of the hollow body (31) and inserted in the stator (20) and is rotatable about the stator (20). Several blades (33) are radially formed on an outer periphery of the hollow body (31).

The cover (40) is mounted on the housing (10) and has an opening (41) defined therethrough. External air also can flow in the housing (10) through the opening (41).

The rotor (30) is rotated counter-clockwise and each blade (33) is curved counter-clockwise. The blade (33) has a convex outer surface (34) and a concave inner surface (37). A first cutout (35) is defined at a bottom side and a proximate end of the blade (33) to prevent the blade (33) from meeting elements on the circuit board (21). A second cutout (36) is defined at an upper side and a distal end of the blade (33) to prevent the blade (33) from meeting the cover (40). An upper part behind the second cutout (36) of the blade (33) is extended in the opening (41). An area of the upper part behind the second cutout (36) substantially equals that of the first cutout (35), so that the overall area of the blade (33) is not decreased despite the cutouts (35, 36). A plane surface (38) is formed on the concave inner surface (37) and at the distal end of the blade (33).

A curved angle (θ) of the blade (33), between a line (a) through the center of the rotor (30) and a root (P1) of the convex outer surface (34) and a line (b) through the root (P1) and a tip (P2) of the convex outer surface (34), is between 30° to 40°. Two adjacent blades (33) have a distance (c) from the plane surface (38) of one blade (33) to the convex outer surface (34) of the next blade (33). The distance (c) is significantly wider than a distance (d) between two adjacent conventional blades without the plane surfaces (38) to increase the blowing capability of the cooling fan.

When the cooling fan is operated, air flows in the housing (10) via the notches (14) and the opening (41) and blows out by the blades (33) through the outlet (131).

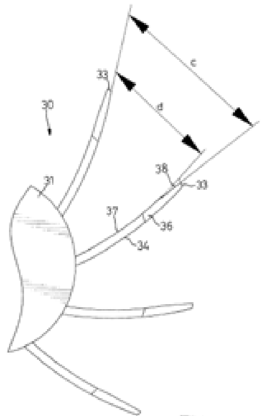


FIG.5

The blades (33) can be used in another cooling fan. The cooling fan has a base (50) with a bottom plate (51). A plurality of fins (52) is formed on the bottom plate (51) and an air inlet (53) is defined at the center of the bottom plate (51). The rotor (30) is assembled on a bracket (54) and the bracket (54) is mounted on the fins (52) of the base (50). The blades (33) are formed on the outer periphery of the rotor (30). A cover (55) is mounted on the bracket (54) and has an opening (56) defined therethrough. The blades (33) are partially exposed from the opening (56).

When the cooling fan is operated, air flows through the base (50) via the inlet (53) and the opening (56) and blows out by the blades (33) through the gaps between the fins (52).

From the above description, it is noted that the invention has the following advantages:

1. Because two air inlets—the notches (14) and the opening (41)—are defined in the cooling fan, air flow-in capability is large.

2. Because the blades have optimized angle and curves, the cooling fan has a large blowing capability and a good radiating effect.

3. Because the blade has cutouts defined therein and can partially extend in the opening of the cover, the height of the cooling fan is small and the cooling fan is thin.

Piezofan and Heat Sink System for Enhanced Heat Transfer,

US 8,322,889 B2 Petroski, James

Piezoelectric fans operate as a vortex shedding device. U.S. Pat. No. 4,498,851 nicely describes vortex shedding as a process where air is prevented from being sucked around a piezoelectric fan blade tip when its motion reverses. Vortex shedding is based on the fact that air displaced from the front of a moving blade rotates so rapidly that the air is unable to reverse its direction of rotation when the blade reverses its motion. If the rotation is not sufficiently rapid, the vortex can reverse its direction of rotation to be sucked around the blade tip instead of leaving the blade.

In the vortex shedding action, a blade 10 of a piezoelectric fan is centered and moving upward at maximum velocity as indicated by arrow 12, and air is being sucked downward around the blade tip as indicated by arrow 14. While this is happening, a previously shed vortex 16 is moving to the right below a center line 18 of the blade (the center line being when the blade 10 is at rest). The blade 10 is beginning to curve upward at about one quarter amplitude. The air is being sucked around the blade tip into a vacuum on the back side of blade 10 and the new vortex 14 a is beginning to form while the old vortex 16 is moving farther to the right. The blade 10 nears an upper end of its travel, leaving a fully formed vortex 14 b in its wake, with vortex 16 still moving outwardly.

Blade 10 has reached its full upward excursion and it has stopped moving and is about to reverse with the fully formed vortex 14 b still in its wake and the previously formed vortex 16 still moving to the right. The blade 10 then starts downwardly again. The vortex 14 b is rotating too rapidly to reverse this motion and it is therefore expelled from the blade area by the new airflow around the blade 10. Upward flow 20 continues to gain speed as air flows into the vacuum behind the blade and the previous vortex 14 b is now clear of the blade wake and gaining speed. The blade 10 accelerates towards its

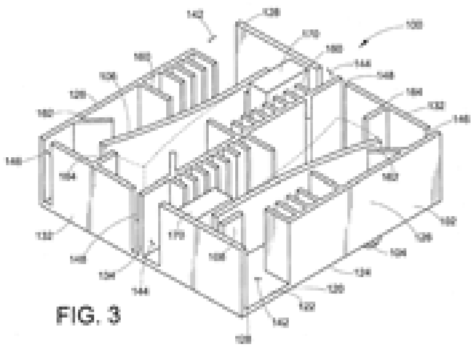
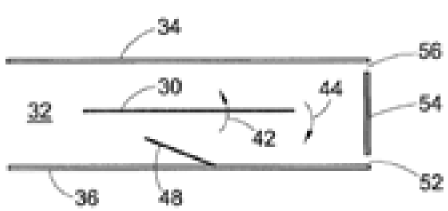
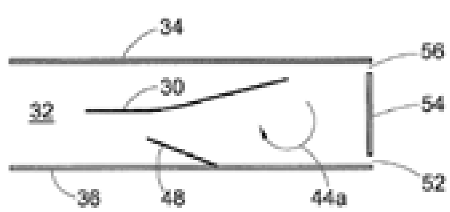


FIG. 3

center position while the air flowing into its wake indicated by arrow 20 is developing a new vortex. The blade 10 centered and moving downward at maximum velocity as indicated by arrow 22, the air being drawn into the vacuum of the wake has developed into a full vortex 20 b. Finally, the blade 10 is moved further downward, feeding more air into vortex 20 b in its wake. The two previous vortices 14 b and 16 are moved toward the right, rotating in opposite directions, one above the center line 18 the other below the center line 18 of blade 10. In this way, a line of oppositely rotating vortices is generated resulting in a highly directional stream of air.

U.S. Pat. No. 4,498,851 indicates that if the vortex shedding effect is disturbed by obstructions in the area, then the air flows from the forward surface of the blade around its trailing edge to the rearward surface of the blade when the motion of the blade reverses. Accordingly, there is only circulation around the trailing edge of the blade and very little outward flow.

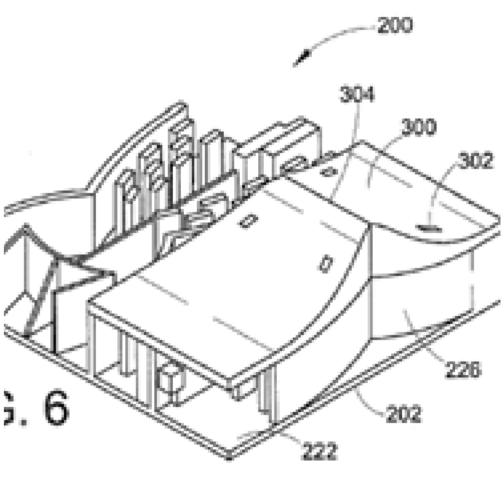




In some instances, however, it is desirable to provide ducts or channels, i.e. obstructions according to U.S. Pat. No. 4,498,851, to direct the air flow. This may be desirable when certain components are to be cooled by the piezoelectric fan. U.S. Pat. No. 4,498,851 does not provide any teaching for directing air flow generated by a piezoelectric fan where ducts and channels are desired.

The blade 30 of a piezoelectric fan disposed in a channel 32 defined by a first side wall 34, a second side wall 36 and a base wall (not numbered) that the side walls extend upwardly from. The blade 30 of the piezoelectric fan is centered and moving upward as indicated by arrow 42, and air is being sucked toward the second wall 36 around the blade tip as indicated by arrow 44. The blade 30 nears its maximum stroke of its travel, leaving a nearly fully formed vortex 44 a in its wake. The blade 30 then starts downwardly again. A fully formed vortex 44 c is compressed against a constriction (formed by a constrictive member 48 extending into the channel 32 from the second side wall 36) and is expelled from an outlet 52 of the channel as the blade 30 continues to move toward the second side wall 36. The constrictive member 48 is shown attached to the second side wall 36; however, the constrictive member can simply extend upwardly into the channel 32 from the base or the constrictive member may depend downwardly from a lid that at least partially covers the channel. An example of a lid will be described in more detail below.

One outlet 52 is defined between a baffle 54 and the second side wall 36. An additional outlet 56, which can operate as an inlet (the first mentioned outlet 52 can also operate as an inlet) is defined between the baffle 54 and the first side wall 34. The baffle can also depend downwardly from a lid that at least partially covers the channel. The vortex 44 a is shaped in the channel 32 to increase the velocity of the air leaving the channel, which allows more heat to escape from the channel. The constriction reduces the cross-sectional area (Ac) of the channel at the constriction as compared to the cross-sectional area of the channel both upstream of and downstream from the constriction. The baffle 54 further limits the cross-sectional area of the channel where the baffle is located (Ao). Because of the conservation of momentum and that the air is not traveling quickly enough to be compressed, the velocity of the air moving through the outlet 52 is much quicker than if the baffle 54 were not present. Nevertheless, if desired the baffle 54 need not be present. The constriction in the channel 32 precludes the air vortex from moving further to



the, thus avoiding the problem of recirculation with very little outward flow as discussed in U.S. Pat. No. 4,498,851.

A device 100 having enhanced heat transfer capabilities includes a heat sink 102, an electronic device 104 (or a plurality of electronic devices) in thermal communication with the heat sink, a pair of fan blades 106 connected to the heat sink, and a pair of piezoelectric elements 108 attached to a respective blade. The heat sink 102 includes a plurality of walls defining a pair of channels 112 through which air flows to transfer heat generated by the electronic devices 104. The components and configuration of each channel 112 are the same except that one channel and the elements associated with it are rotated 90° with respect to the other. The blades 106 can oscillate 180° out of phase with each other such that the complementary back and forth motion of the two blades 106 provides balancing and prevents vibration of the device 100. The blades have a generally rectangular configuration having opposite planar surfaces.

The electronic devices 104 are light emitting diode devices ("LEDs"). Other electronic devices that generate heat, in addition to or in lieu of LEDs, can also be attached to the heat sink 102. In the depicted embodiment, the heat sink 102 includes a base 120. The base 120 includes an upper planar surface 122 and a lower planar surface 124. Alternatively, the base 120 need not be planar. The LEDs 104 attach to the lower surface 124. A thermally conductive support, such as a metal core printed circuit board, can be interposed between the LEDs 104 and the lower planar surface 124. The circuit board, or other similar device, includes circuitry in electrical communication with a power source to provide electricity to the LED or other electrical device.

Outer side walls 126 extend upwardly from the base 120. Inlet end walls 128 also extend upwardly from the base 120 adjacent to an attached end of the blade 106. Outlet end walls 132 extend upwardly from the base 120 adjacent to a free end of the blade 106. The inlet end walls 128 and the outlet end walls 132 are generally perpendicular to both the base 120 and the outer side walls 126. An inner wall 134 is positioned between each blade 106 and extends upwardly from the base 120. The inner wall 134 is disposed generally parallel to each of the outer side walls 126 and perpendicular to the base 120 and the end walls 128 and 132.

The piezoelectric material 108 attaches to the blade 106 opposite the free end (and in the depicted embodiment adjacent to pedestal 170). Alternatively, the piezoelectric material 108 can run the length or a portion of the length of the blade 106. The piezoelectric material 108 comprises a ceramic material that is electrically connected to the power source in a conventional manner. As electricity is applied to the piezoelectric material 108 in a first direction, the piezoelectric material expands, causing the blade 106 to move in one direction. Electricity is then applied in the alternate direction, causing the piezoelectric material 108 to contract thus moving the blade 106 back in the opposite direction. Alternating current causes the blade 106 to move back and forth continuously in the channel 112. The blade 106 and the angled walls 162 are configured such that the blade does not contact the angled walls as it moves back and forth in the channel 112.