Design and Construction of a Movable Shield for a Barium Oven

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***Abstract*—A moveable shield was created in order to block large chunks of barium which come off a barium oven when it is initially turned on. This shield will prevent chunks of barium from blocking the small hole through which barium ions should be entering the chip trap. Two different actuation mechanisms were explored for the shield: first, a nitinol wire and second, a bimetal strip. The nitinol wire was found to be unsuccessful but the bimetal strip was found to be simple and reliable. Vacuum testing was performed for a bimetal strip setup and data was collected on the curvature of the metal as a function of the current applied to it. Based on this testing, any amount of current between 1 and 2 amps is predicted to be sufficient to cause the shield to block the barium oven, while passing no current through the bimetal will unblock the oven, allowing the trap to be loaded.**

I. Background

ION trapping has many potential applications in atomic physics. It is possible to use trapped ions to create ion-photon entaglement. This entanglement can be used to run a loophole-free tests of Bell's Inequality. Another application of ion trapping is the creation of a scalable quantum computer. Trapped barium ions can be used as qubits where the spin-up and spin-down states of the outermost electron correspond to the 0 and 1 states in a conventional computer. Using superposition of states, algorithms for quantum computing have the potential to be highly more efficient than traditional computing algorithms. For example, Shor's algorithm would allow a quantum computer to factor large numbers much faster than is possible with any currently existing computer. The implementation of such an algorithm would have profound implications for computer security since current encription schemes rely on the impossibility of factoring very large numbers efficiently.

II. Physical System

In order to trap individual barium ions, we must first generate a stream of barium atoms. This is accomplished using a barium oven in which solid chunks of barium are heated to very high temperatures, causing an atomic beam to be emitted. Directly above the barium oven there is a small hole through which the barium atoms can enter the chip trap.

One pitfall of the above design is that as the oven is initially being heated relatively large chunks of barium are released. These pieces are large enough to block the hole through which atoms should be escaping, and therefore derail the actual experiment. In order to solve this problem, we created a shield which is held over the oven while it is initially being heated, then moved out of the way when experiments are ready to begin. This shield may also be used repeatedly to block atoms from entering the system after an ion has been trapped, but allow more atoms through at a later point in time if a trapped ion is lost.

III. Design with Nitinol Wire

The first iteration of our design used Nitinol wire to actuate the movement of the shield. Nitinol is a nickle-tin alloy that belongs to a larger class of materials known as shape-memory alloys (SMAs). These alloys can be ”trained” by holding them at high temperatures for at least five minutes and then cooling them quickly. While cold, the SMA can be bent into whatever shape is desired and when the SMA is heated above an activation temperature it will return to the shape it was trained to.

Figure 1 shows a schematic of the original design with Nitinol wire and springs holding the shield. In this design, the nitinol is trained into a sharply bent shape and is looped through one end of a sheet metal shield. Springs are attached to the other end of the shield such that they pull and cause the nitinol to unbend when it is cold. This design was tested and found to be incapable of creating repeatable movement over a large enough distance. The pulling strength of the nitinol wire when heated was not significantly greater than the strength with which the cold nitinol wire resisted shape changes. Therefore, any springs which were weak enough to be extended by the hot nitinol wire were also too weak to extend the cold nitinol wire significantly.

Two other nitinol setups were also tested and found to exhibit the same shortcoming. In one setup, two different pieces of nitinol wire were attached on either end of the shield. In this case, the pieces could be made to have different strengths by heat training them for different amounts of time. However, this variation in timing affected both the hot strength and the cold strength of the wire. As a result, regardless of the conditions of the shape setting, alternate heating of the two wires caused the system to reach an equilibrium configuration in which neither wire could create any further movement when heated. The final nitinol configuration tested was to shape set the nitinol into a helix and attach it to the shield such that it pulled against a spring. This setup was also found to be infeasible for the same reasons as the original setup.

IV. Use of Bimetallic Strips

A. Design

Bimetallic strips are strips of metal in which two metals with different coefficients of thermal expansion are fused together

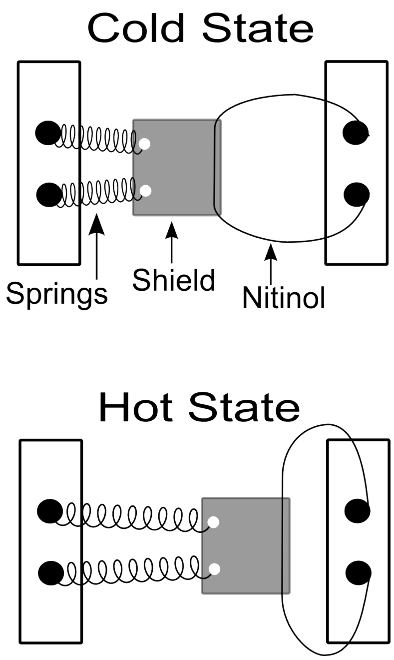


Fig. 1. Original shield setup design. Sheet metal shield pulled in opposing directions by nitinol wire and springs.

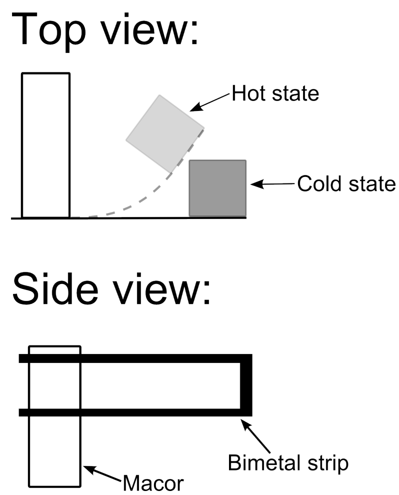
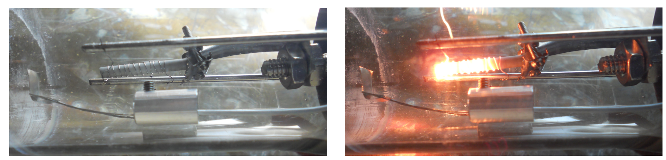
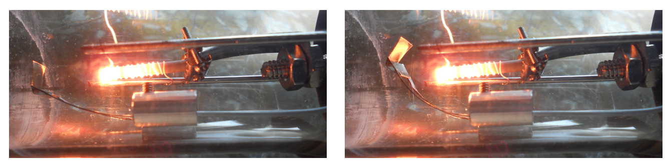


Fig. 2. Schematic of shield setup using bimetal strips.



(a) No current, oven off (b) No current, oven on



(c) 1 amp current, oven on (d) 3 amps current, oven on

Fig. 3. Barium oven, bimetal strip and shield inside vacuum. Heat from the oven does not cause the bimetal strip to bend, but resistive heating does when a current of 1 amp or more is applied.

side-by-side. When a bimetallic strip is heated, one side of it becomes longer than the other, causing the strip to curl into an arc such that the metal with greater thermal expansion is on the outside. Upon cooling, the bimetal will automatically uncurl as the two sides return to equal lengths. In our second design, we used this motion as the driving mechanism for the shield.

Figure 2 shows a schematic of the setup used for the bimetalic strip. Precise dimensions are shown in Appendix A. Bimetallic strips were manually cut into the desired length and shape, which was chosen in order to make resistive heating possible with reasonable levels of current. The bimetal strip was then screwed into a macor block designed to fit underneath the chip trap in the current trapping setup. Heating was accomplished by passing current through the bimetal strip. Greater amounts of current were found to induce more significant curvature in the metal.

B. Vacuum Testing

A simple vacuum test of the bimetal setup was performed in a bell jar. Due to space constraints, the macor block was not included in the vacuum test. Instead, the bimetal strip was connected directly to two feedthrough electrodes. A barium oven was also included in the vacuum test in order to ensure that the heat from the oven would not cause the bimetal to bend. Images from the vacuum test are shown in Figure 3. It is clear from Figures 3(a) and 3(b) that radiative heat from the barium oven is not sufficient to cause bending of the the bimetal. As shown in Figures 3(c) and 3(d), the bending of the bimetal strip can be reliably controlled by the amount of current applied to it. Noticeable bending begins around 0.5 amps of current and the curvature increases continually as greater amounts of current are applied. The bimetal will consistently return to the same shape each time a given amount of current is applied. These results indicate that a bimetal strip will be a reliable actuation mechanism for shielding the barium oven.

C. Curvature Predictions

Once the oven shield is put in place and pumped to ultrahigh vacuum, it will be difficult for an observer to view the oven shield. Therefore, it is necessary to be able to predict the bimetal curvature as a function of applied current. This prediction will determine how much current must be applied in order for the barium oven to be shielded. In order to make this prediction, we measured the curvatures of the bimetal strip under three conditions: in vacuum, in the vacuum setup but at atmospheric pressure and in the final setup at atmospheric pressure. The results of these measurements are shown in Figure 4. It is seen that for currents between 1 and 4 amps, the radius of curvature of the bimetal depends exponentially upon the current applied.

We also see in Figure 4 that the bimetal bends more (has a smaller radius of curvature) when heated in vacuum than it does when heated in air. This is expected because in vacuum the bimetal strip is not cooled through convection as it is in

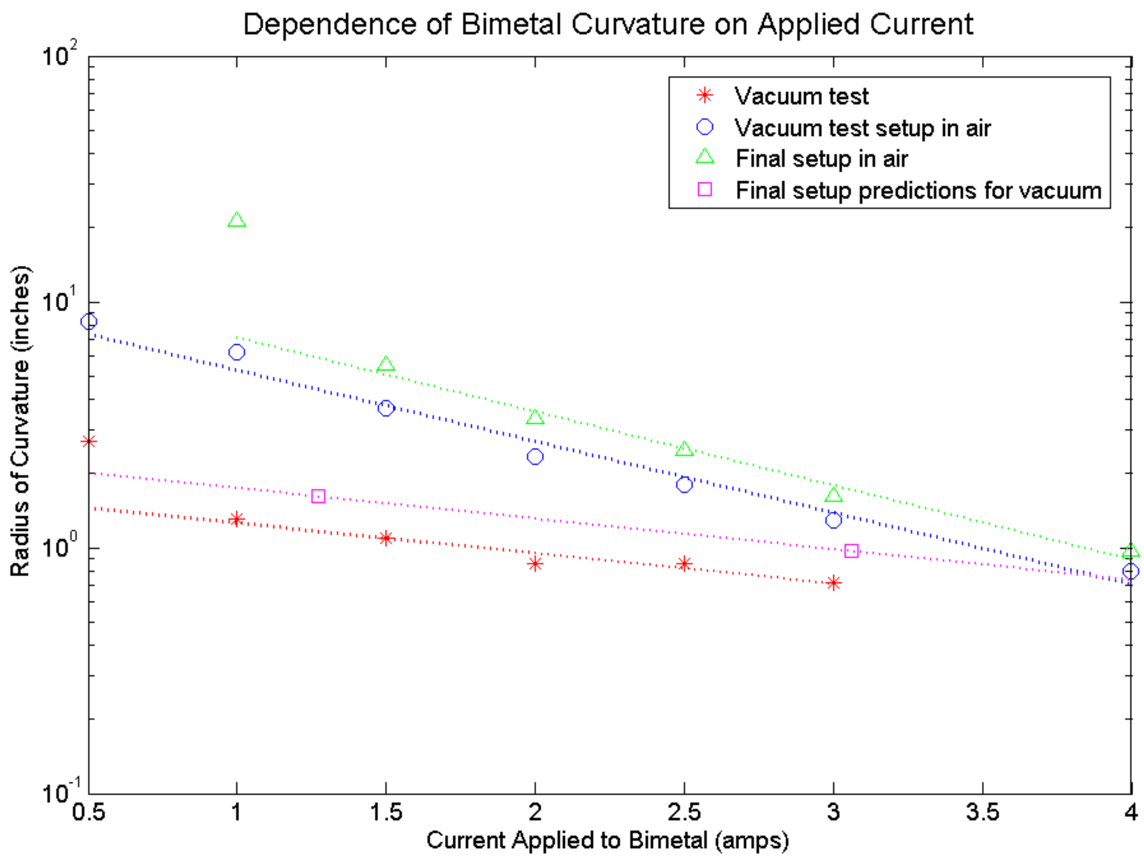


Fig. 4. Bimetal curvature as a function of current applied.

air, so the strip reaches higher temperatures in vacuum, which causes it to bend more. We also see from comparison of the two curvature tests run in air that the bimetal strip to be used in the final setup consistently bends less for a given amount of current than the bimetal strip that was used in the vacuum test (this is shown by the vertical offset between the green and blue lines). This is most likely due to the different lengths of the two bimetal strips. Therefore, we predict that the same amount of offset will be present when comparing the final setup in vacuum to the test setup in vacuum. The predicted purple line in Figure 4 was made based on this assumption.

In air, the bimetal strip in the final setup required a current of at least 2.5 amps in order to bend enough to block the barium oven. 3 amps of current was ideal, as it reliably centered the sheet metal shield over the barium oven, and 4 amps was the maximum that could be safely applied while ensuring that the bimetal strip did not come in contact with the oven. By matching the radius of curvature observed at each of these current levels to the predicted radius of curvature in vacuum, it was found that the maximum current that should be applied to the bimetal strip in vacuum is 3 amps, and the ideal current to completely cover the oven (equivalent to 3 amps in air) is 1.3 amps. There is no prediction for the absolute minimum current necessary (equivalent to 2.5 amps in air), as that number would be lower than 1 amp, and therefore not within the domain for which our linear predictions are reliable. From these predictions, it is suggested that between 1 and 2 amps of current should be applied to the bimetal strip in vacuum in order to fully block the barium oven, and no current should be applied when loading the trap.

V. Conclusion

This paper presented the design and testing of a movable sheet metal shield to be placed in an ion trapping system. The shield is actuated using a bimetal strip, which was found to be capable of consistent, repeated movement when resistively heated. When activated with current, the bimetal strip bends and moves a sheet metal shield over the barium oven, thereby preventing barium chunks from clogging the entrance to the chip trap. When current is removed, the bimetal strip returns to its original shape, unblocking the oven and allowing ions to be loaded into the trap. Based on vacuum testing, it is predicted that for the bimetal strip to be used in the chip trap setup, a any current between 1 and 2 amps will reliably cause the barium oven to be shielded.

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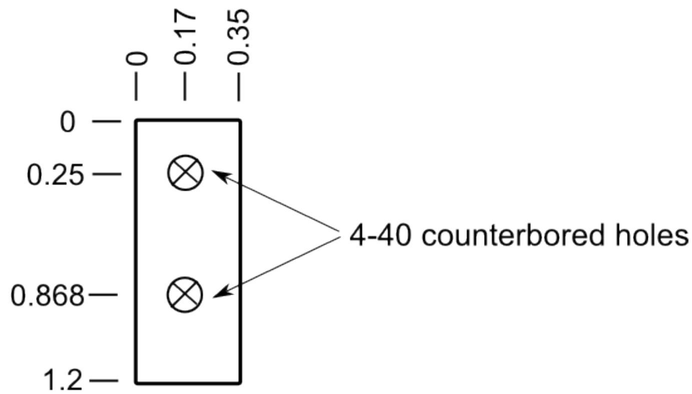
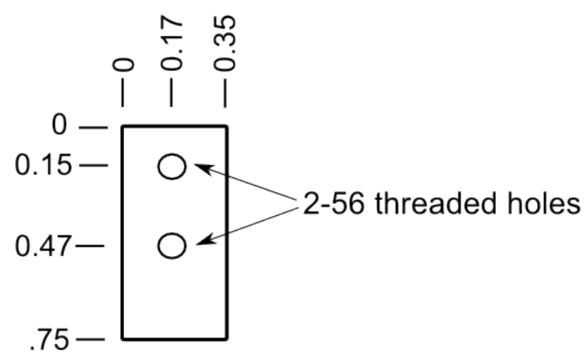
Appendix A
Dimensions of Macor Block

Top view:



Side view:



All measurements are in inches.