Piezo actuators are today the core component in modern, energy-efficient fuel injection systems. TDK now presents its third generation of EPCOS piezo actuators with copper internal electrodes, which offer both improved performance and higher cost-efficiency.

The series production of EPCOS piezo actuators for fuel injection systems began in 2000. Since then, many more than 100 million piezo actuators have been shipped. In order to reduce the costs of piezo actuators and to increase their ruggedness, the company has been carrying out intensive and successful research work.

In 2003 the first series produced actuators with copper internal electrodes were introduced as a cost-efficient alternative to the original silver-palladium electrodes. This was an important milestone, as the use of palladium in particular causes relatively high costs. TDK is today the only company worldwide that uses the favorably priced copper as the electrode material for actuators. In contrast, our competitors increase the proportion of silver in their electrode material in order to cut costs. This approach, however, can lead to silver migration and the subsequent failure of the actuators, especially in the presence of high humidity.

The drawback of the first generation of piezo actuators with copper electrodes was their somewhat lower piezoelectric coupling of only 63 percent compared to 71 percent for silver-palladium actuators. Piezoelectric coupling is a measure of the ability of the material to convert electrical power into mechanical power. The second generation of the EPCOS piezo actuator with copper electrodes, which was introduced in 2009, featured an increased piezoelectric coupling of 72 percent. Now, the third generation of piezo actuators with copper electrodes has even further improved this key value (Figure 1).
Figure 1:
EPCOS piezo actuators with copper internal electrodes
TDK fulfills the growing technological requirements

The following requirements are the key determining factors for the development of piezo actuators:

- Improved performance of the actuators in terms of elongation and force
- Reduced volume of the component
- Increased robustness and reliability in order to achieve a greater number of switching cycles or elongations
- Higher operating temperatures

With its third generation of piezo actuators with copper electrodes TDK meets these requirements. The basis is a new ceramic material that features a coupling factor of >75 percent and a significantly higher active volume. Table 1 shows the key parameters of the various generations of piezo-ceramic materials for multilayer actuators with conventional isolation zones and predetermined breaking layers.

Table: Comparison of piezo actuator generations and technologies

<table>
<thead>
<tr>
<th></th>
<th>TDK</th>
<th>Competitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack designs</td>
<td>AgPd</td>
<td>Various</td>
</tr>
<tr>
<td>Material class</td>
<td>Soft PZT</td>
<td></td>
</tr>
<tr>
<td>Inner electrodes</td>
<td>Ag75/Pd25</td>
<td>Cu</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>Cu + 1% Pd</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>Ag95/Pd5 to Ag70/Pd30</td>
</tr>
<tr>
<td>Piezoelectric coefficient [pm/V]</td>
<td>800</td>
<td>680</td>
</tr>
<tr>
<td>Piezoelectric permittivity [GPa]</td>
<td>3910</td>
<td>3920</td>
</tr>
<tr>
<td>Young’s modulus [GPa]</td>
<td>27</td>
<td>31</td>
</tr>
<tr>
<td>Piezoelectric coupling [%]</td>
<td>71</td>
<td>63</td>
</tr>
</tbody>
</table>

The ceramic material for third generation piezo actuators with copper electrodes and high active volume combines improved performance with cost efficiency.

The sintering process is the key to manufacturing piezo actuators with copper electrodes. The entire temperature profile of the partial pressure of the oxygen must be maintained within a very narrow tolerance field in order to avoid the reduction of the lead oxide of the ceramic as well as oxidation of the copper. This process, which is proven for many years, is also used in the third generation of EPCOS piezo actuators with copper electrodes.
High active volume thanks to selective etching

In the design of the third generation of copper piezo actuators with a maximum ratio of active volume, the isolation zones have been minimized and predetermined breaking layers that are needed in most conventional actuator designs have been eliminated. The piezoelectric coefficient (elongation per layer) of the multilayer actuators then increases from 840 pm/V to 915 pm/V. The high active volume technology thus achieves the maximum possible volume efficiency.

In the latest actuators, selective etching of the internal electrodes is used to produce the isolation zone, so that the thickness of the isolation zone can be limited to 100 µm (Figure 2). In conventionally manufactured actuators, this region has a thickness of at least 400 µm. Not only does this dramatic reduction and the elimination of predetermined breaking layers result in a significantly higher active volume, the performance increases by 20 percent compared to conventional designs (Figure 3).

Figure 2:
Cross-section of a third generation EPCOS piezo actuator with copper electrodes:
Selective etching of the isolation zones allows a higher active volume to be attained.
Figure 3:
Significantly improved performance:
Performance comparison of third generation EPCOS piezo actuators with copper electrodes with conventional piezo actuators of the same size. Thanks to the higher active volume, both the elongation and force have been significantly increased.

The selective etching also prevents polarization cracks of the kind that occur in conventional actuators with additional isolation layers and predetermined breaking layers. This leads to a dramatic increase in reliability.
Superior stability and reliability

For contacting the external electrodes, TDK has developed a new lead-free high melting metal bond that even at high temperatures exhibits no embrittlement and thus no loss of contacting. This new bond even proves to be more reliable than a lead-based solder for electrode contacting. As a consequence, the new piezo actuators survived a 2000-hour test at 200 °C with no signs of embrittlement. By contrast, conventional solder contacts already failed after 1500 hours at temperatures of only 180 °C.

One of the key criteria for the use of new piezo actuators is the operating life, or the maximum achievable number of cycles even under harsh operating conditions such as high temperatures and high air humidity. The third generation of EPCOS piezo actuators with copper electrodes stands out here thanks to their outstanding stability and reliability (Figure 4).

Figure 4:
Reliability test of third generation of EPCOS piezo actuators with copper electrodes:
Clearly recognizable: EPCOS copper piezo actuators of the third generation attain a billion switching operations without failures at 170 °C. In contrast, silver-palladium actuators already show significant failure rates under these conditions.

Thanks to their significantly enhanced performance, the new third generation EPCOS piezo actuators with copper electrodes make a critical contribution to increasing the reliability and long operating life of injection systems for diesel and gasoline.