RESEARCHHIGHLIGHT
SANDIA/CALIFORNIA

# Developing New High-Performance Alloys for LIGA Microsystem Applications

Sandia is investing considerable resources in developing microsystem technologies. One particular technology is the LIGA process in which small metallic parts are produced via electrodeposition into precisely fabricated mold cavities.

The LIGA acronym is derived from the German words Lithographie (lithography), Galvanoformung (electroplating), Abformung (molding), and the process is capable of mass producing structures that measure 1 to 2 mm in height with micron level resolution in lateral features.

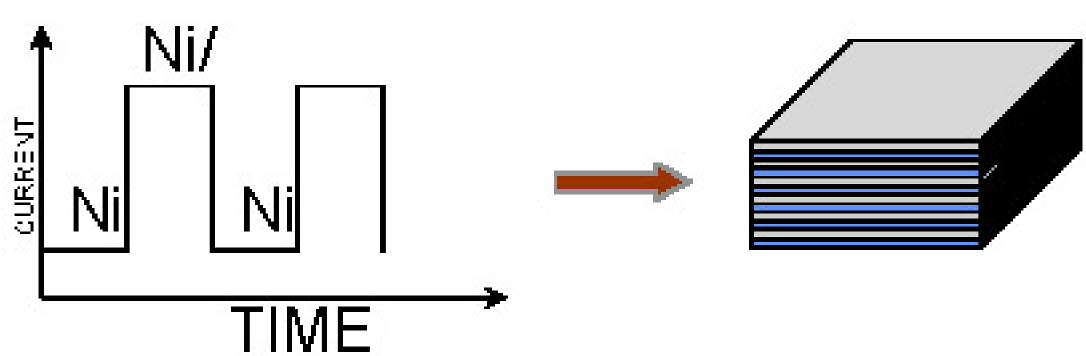
The electrodeposited materials are often required to have high strength ( 800 MPa) and good ductility to function properly in a microsystem. Additional requirements may be placed on such electrodeposited materials, viz., very low plating-induced stresses, a near room temperature plating process (necessary to maintain tolerances in lateral dimensions), through-thickness uniformity and often, the retention of ductility after thermal exposure.

Unique to the LIGA process is the requirement that the above properties and characteristics be realized in high aspect ratio (>10) and thick section deposits (200 µm to 2 mm ).

**Background—Limitations of Prior Materials and Processing Techniques:**

Various elemental or alloy thick film deposits may meet some, but not all of the criteria indicated above. In one instance, NiCo alloys are readily electrodeposited and exhibit high yield strengths. But since cobalt deposition rates are very dependent on local mass transport conditions, electrodeposition through a thick mold results in compositional non-uniformities. Since the strength of these alloys depends directly on the cobalt content, variations in hardness and strength result, rendering the material useless for structural microsystem applications. Such non-uniformities may be remedied, but only if very low average deposition rates are employed. Further, the high cobalt concentration required to realize the necessary strengths results in intractably high film stresses that can fail the mold or cause the deposit to debond from the substrate.

Another way to achieve a high-strength electrodeposited material is by using electrolyte bath additives such as saccharin to produce fine grain-sized nickel. The addition of saccharin to the electrolyte results in the incorporation of 300 to 600 wt. ppm sulfur in the electrodeposited nickel. While the resulting electrodeposit has low stress, high strength, good ductility, compositional and property uniformity, the high sulfur content renders it susceptible to catastrophic embrittlement upon its exposure to even modestly elevated temperatures. As a consequence of this behavior, sulfur-bearing electrodeposited materials may not be used in any application where temperature excursions  200 °C can occur.



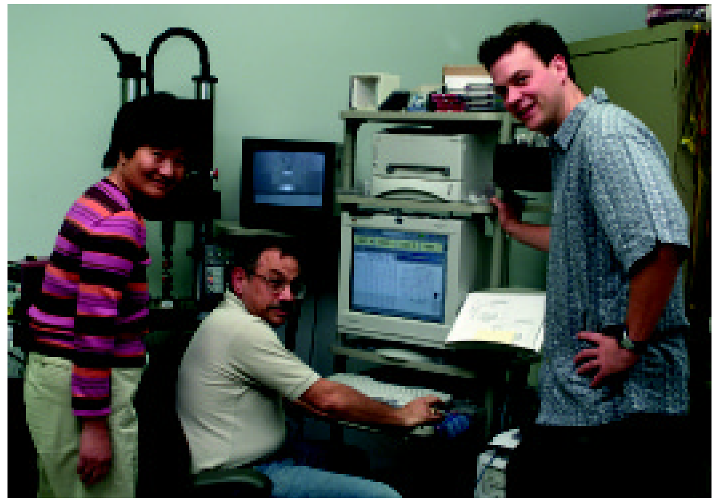

Pulse-plating between low- and high-current densities produces a compositionally modulated alloy comprised of successive layers of nickel and NiMn alloy films.

**Accomplishment—The Development of a High Strength, Heat Resistant Alloy**

We developed a new nanostructured, compositionally modulated NiMn alloy that remedies all of the shortcomings described above. While earlier work suggested that electrodeposited NiMn alloys exhibited at least some of the required properties and characteristics, a number of serious problems were revealed—principally the development (under constant-current plating conditions) of high residual stresses as the thickness of the deposit increased. Indeed, these high plating stresses often lead to delamination of the deposited film from the deposition substrate.

Critical to the success of this current effort was the discovery of a way to moderate these very high plating stresses. The technique involves pulse plating to produce a compositionally modulated material consisting of alternating layers of high-strength, highly stressed NiMn alloy and lower-strength pure nickel. This can be achieved because the deposition of manganese is dependent on the applied current density; at low current densities, little or no manganese is codeposited, while at higher current densities, manganese is deposited at concentrations approaching 1%. The Figure shows the process schematically. The pulse durations are chosen so as to result in layers that are only a few nm in thickness, rendering the deposit a true nanostructured material. It was thought that by depositing the alloy in a layered fashion with alternating nickel and NiMn layers, plating stresses would be reduced by the deformation accommodation of the softer nickel layers and that overall, a high-strength NiMn alloy with lower plating-induced stress would result.

The approach has been shown to be successful. Thick section electrodeposits up to 1.6 mm thick have been successfully produced with 100% part yield. Mechanical properties of the NiMn alloy plated using this process exceed component requirements. Yield strengths are in excess of 900 MPa with greater than 6% total ductility. The presence of the soft, low-stress nickel layers does not seriously compromise the post-annealing, strength retention of the alloy. Indeed after a 1-hour, 600 °C heat treatment, for a NiMn alloy specimen plated with the process shown above, there is only a 15% loss in yield strength while ductility improves to 10%. In contrast, a Ni-only deposit would suffer a 75% loss in yield strength subsequent to a similar heat treatment rendering it useless as a structural material.



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Nancy Yang (left) received her MS from the University of Pennsylvania in material science in 1976 and joined Sandia in 1988.

An additional inherent benefit of the NiMn system is the fact that the manganese is codeposited under kinetic control; i.e., local variations in mass transport do not affect the manganese incorporation rate. As a result, the NiMn composition is constant through the feature thickness in both low- and high-aspect ratio mold cavities.

**Significance**

This material system is expected to form the basis for many LIGA applications by satisfying the principal processing and materials requirements for many LIGA microsystems namely: near ambient temperature deposition of low stress, thick-section films, through-thickness compositional uniformity, as-plated yield strength >800 MPa, ductility retention after heat treatment and low loss of strength after heat treatment.