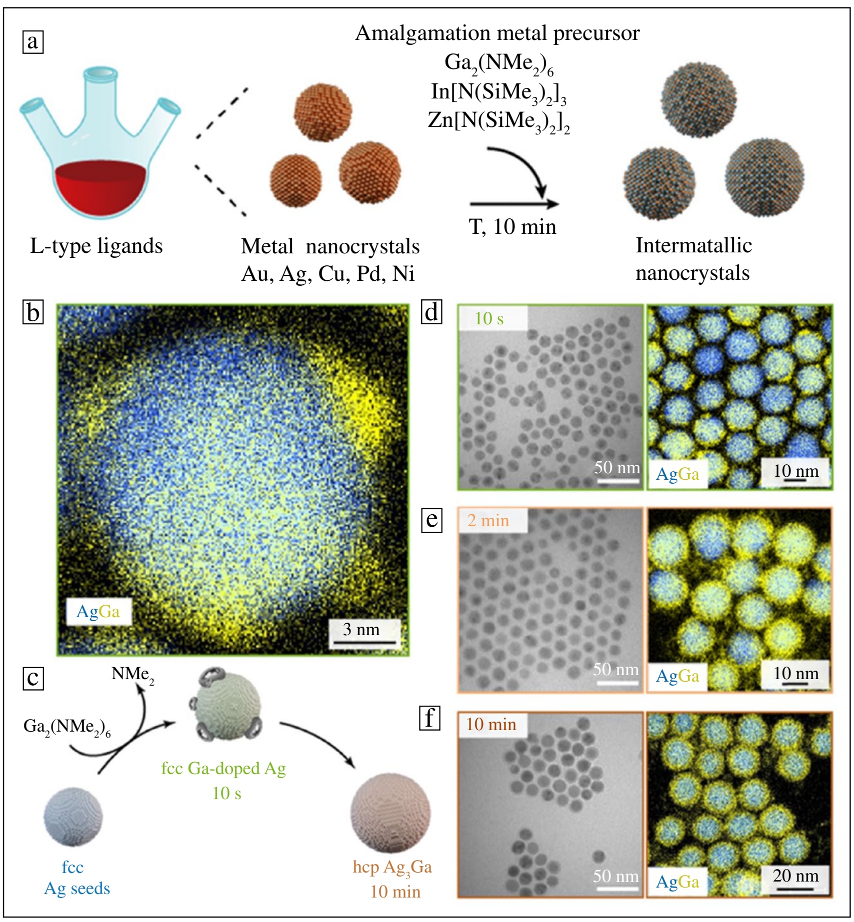
Amalgamation seeded growth yields intermetallic nanocrystals

Scientists at ETH Zürich have developed a new method they term "amalgamation seeded growth" in order to synthesize monodisperse intermetallic nanocrystals (NCs) with excellent control over the nanoparticle size and composition. This work was reported in a recent issue of *Science Advances* (https://www.science.org/doi/10.1126/sciadv.abg1934). This approach opens up a multitude of possibilities for these materials in different applications. These intermetallic NCs have extensive potential applications in catalysis, electronics, thermoelectric devices and memory technologies, superconductivity, energy storage and conversion technologies, photonics, life sciences, and medicine. As intermetallic NCs are difficult to synthesize due to challenges such as the different reduction potentials between metals, an amalgamation of metals was performed. To produce NCs with two different metals, a liquid metal penetrates a solid one via amalgamation, making it possible to build intermetallic NCs with different properties.



(a) Amalgamation reaction, converting monometallic seeds into intermetallic nanocrystals, (b)–(c) amalgamation schematics, and (d)–(f) amalgamation at 10 s, 2 min, and 10 min. Credit: *Science Advances*. fcc, face-centered cubic; hcp, hexagonal close-packed.

Although there are thousands of combinations of metals that can be used to form NCs, only a few combinations have worked. Jasper Clarysse and coworkers from the Institute for Electronics at ETH Zürich have introduced a technique to amalgamate different metal seeds (Au, Ag, Cu, Pd, and Ni) with Ga, In, and Zn to obtain high-quality intermetallic NCs. The reaction starts with a dispersed NC containing a single metal. Then these NCs are added to a second metal in molecular form (metal amides and silylamides). Both metals are mixed and heated to $T > 260°C$ for 10 min (see **Figure**). This high reaction temperature causes the metal amide bond to break up, allowing the liquid metal to penetrate the other metal NCs, forming a new crystal lattice (see **Figure b–f**).

With this technique, the researchers produced different intermetallic NCs such as gold–gallium, copper–gallium, nickel–gallium, and palladium–zinc and achieved quantitative control over the NC compositions. The proportion of the NC metals can be controlled with the amount of amalgamating metal added. This determines the stoichiometry of the resulting intermetallic NCs yielding NCs with different proportions such as $AuGa_2$, AuGa, and Au_7Ga_2 (Au:Ga = 1:2, 1:1, and 7:2, respectively).

The researchers also demonstrated that uniformity in size of the NCs is preserved upon amalgamation by comparing the size of the final intermetallic NCs (Ag_3Ga, Cu_2Ga, Ni_2Ga_3, $AuGa_2$, and PdGa) with the size of the initial NCs.

The researchers envision that amalgamation can be used to generate NCs of other intermetallic crystals of interest for various applications.

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