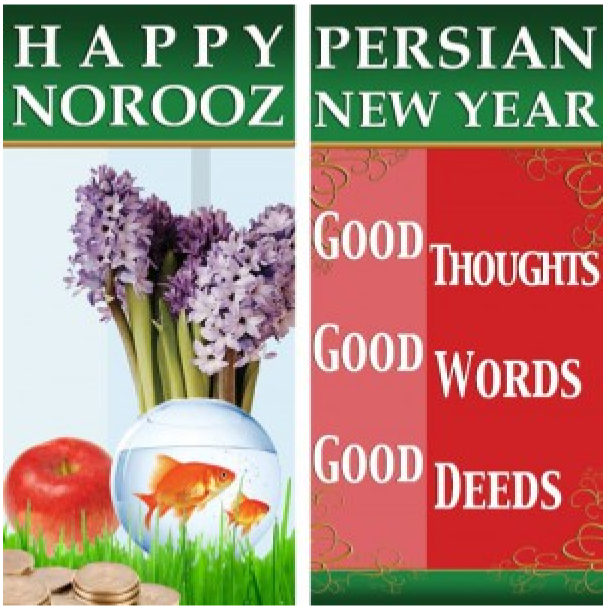
HAPPY NOWRUZ

Nowruz (Persian: نـــــوروز, IPA: [nouˈɾuːz], meaning “[The] New Day”) is the name of the Iranian New Year. Nowruz marks the first day of spring or Equinox and the beginning of the year in the Persian calendar.

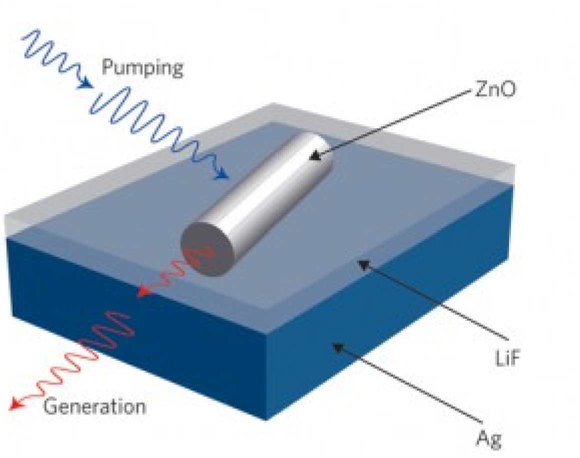


Source: http://en.wikipedia.org/wiki/Nowruz

Plasmonic lasers: On the fast track

The dependence of the output power on the delay indicated that the generated pulse length was less than a picosecond, which suggested an extremely high direct-modulation rate. Moreover, finer interferometric measurements of the spectral composition of the radiation allowed the authors to establish that the generated pulse was even shorter; on a subpicosecond scale. Thus, this spaser has more than a terahertz in the direct modulation bandwidth — a record-setting achievement.

Presently, fundamental physics of plasmonic nanolasers is rather well understood and widely investigated, both theoretically and experimentally. Although there is still a lot to study, especially with respect to new materials and designs, the attention will naturally shift towards applications, as the recent implementation of spasers in the detection of explosives suggests[10]. In this vein, the type of ultrafast nanolaser demonstrated by Sidiropoulos *et al.*[2] will potentially allow for ultrawideband optical communications, as it can be efficiently loaded by an optical plasmonic nanofibre. And by directly modulating them using transistor currents, ultrafast on-chip communications in processors with a terahertz speed may also be possible[12]. Another feasible application is the ultrafast spectroscopy of biological objects, as the sizes of many macromolecules, their complexes and cell organelles are on the same order of magnitude as the transverse size of the spasing mode[2].



Avenues for further improvements in spaser operating properties and applications are ultimately determined by the underlying physics. The spaser speed, for example, is related to the modal volume[11], which is why smaller means faster. In this respect, the ultrafast behaviour demonstrated by

Sidiropoulos *et al.*[2], though unprecedented, is not a fundamental limit. A smaller spaser could even be faster, although further miniaturization may not be possible with the current design. This is most likely due to two peculiarities: first, it works very close to the plasmon frequency, where the losses are relatively large; second, it is based on a continuous metal and is probably leaking its energy into surface plasmon polariton waves, which further increases the losses. So this device may not generate when significantly reduced in size.

Spasers with a nanoparticle as the plasmonic resonator, on the other hand, are known to operate on much smaller scales[4], so these may be the design choice for the faster spasers of the future. How the rate of electron–hole relaxation in the gain medium limits the spaser's direct modulation speed is yet to be studied both theoretically and experimentally. But the achievement reported by Sidiropoulos *et al.*[2] is an excellent launch pad for future progress.

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Nanosphere lithography for device fabrication

Nanosphere lithography (NSL), originally termed ' natural lithography' by its inventors,[1] is becoming a widespread bottom-up technique to pattern solid surfaces at the sub-micrometer and nanoscales. Groups such as Van Duyne's[2] at Northwestern University and others[3] undertook pioneering work on NSL in the 1990s and early this decade, and a growing number of research laboratories around the globe now use the technique in many scientific disciplines. The approach has applications in various materials systems, is fast and scalable to large surface areas, and is inexpensive in terms of equipment and operation. Some variants of the technique have reached a high level of maturity and control. Therefore, it is likely that it will soon be used in device fabrication.

NSL exploits the self-organization of particles at the double- or triple-phase boundary of a colloidal suspension, which consists of a liquid phase (typically water or water-alcohol solutions) and spherical solid particles (polystyrene, polymethyl methacrylate, or silicon dioxide, for example). Suitable suspensions are fabricated by chemical precipitation processes and are commercially available. Particle diameters range from some 10nm to a few micrometers, with size variations of a few percent. The size distribution—among other factors—is of crucial importance for the quality of nanomasks, which determine the lithographic pattern. In the bulk of the liquid the colloidal particles are randomly dispersed and exhibit Brownian motion. However, at the surface, or at the thin menisci of the suspension (as exist at the periphery of a droplet, for example), capillary forces act on the spheres. On flat or slightly curved interfaces this leads to the self-arrangement of spheres in a hexagonally close-packed 2D mono (or double) layer. When this is placed on a solid substrate and dried, the space between each triplet of spheres can be regarded as a mask opening, where the substrate can be modified by adding or removing material using conventional thin-film deposition,[1–5] sputter erosion, or ion implantation[6–8](see Figure 1).

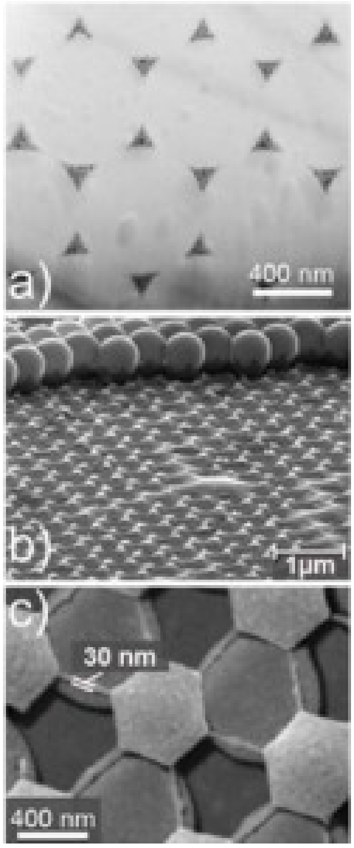

Fig.1. (a) Plane-view transmission electron microscopy bright-field image of an array of thermally evaporated nanocrystalline nickel (Ni) dots (dark) on silicon after removing the nanosphere lithography (NSL) mask. The size of the Ni dots is determined both by the size of the spheres and the clogging effects of the mask openings.[5] *(b) Scanning electron microscopy (SEM) image of zinc oxide nanoparticles and nanowires arranged in an array on a silicon substrate by sputter deposition through a mask of 600nm-diameter polystyrene spheres. The NSL mask is removed in the front, but partially still visible in the background. (c) A regular network of silver-coated organic nanowires created by plasma modification of an NSL double-layer mask of polystyrene beads.*[12]

Usually, the shape of nanoparticles formed by combining NSL and physical vapor deposition techniques is expected to be the shadow projection of the mask opening. However, there are several other influencing factors, such as the angular and energy distribution of the arriving atoms, the materials used (for deposition, substrate, and mask), the substrate temperature (influencing nucleation and crystal growth as well as the dewetting behavior of the deposited material), and the clogging behavior of the mask openings. Therefore, we study the morphology, chemical composition, and crystalline structure of arrays of nano-objects using transmission electron microscopy, and correlate this information to macroscopic properties. The shape of mask openings can be modified using thermal,[9,10] plasma,[11, 12] and ion beam processes.[13,14] Combining this approach with hard mask deposition through NSL masks, subsequent reactive ion etching, and also the combination with angular resolved deposition techniques, we can create numerous complex 2D and 3D motifs arranged in close-packed hexagonal arrays.[9, 12,15]

NSL-created metallic nanostructures have been applied to study the plasmonic behavior of nanoparticle arrays,[2] to create optical metamaterials,[9] and to act as hard masks to pattern substrates for improved semiconductor epitaxy.[15] NSL structures also act as catalysts for the growth of semiconductor nanowires,[4] and can initiate pillar formation in glancing angle deposition of films, among other examples.[16,17]

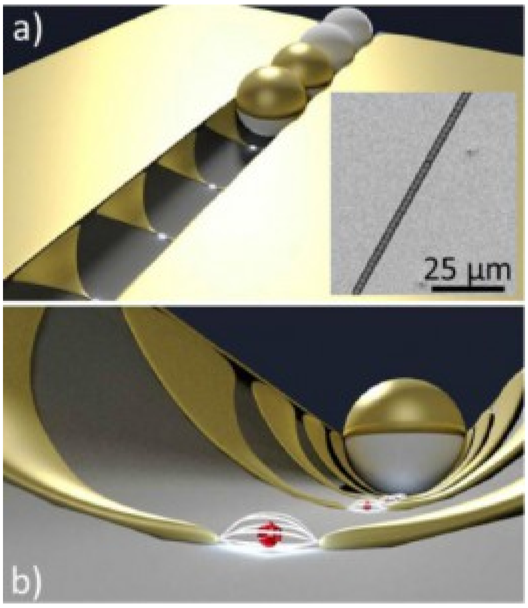

Fig.2. *(a) Schematic presentation of NSL with spheres selectively assembled in a trench. The inset is an SEM image.[18] The spheres at the front have been removed after depositing a metal film. Two spheres at the back are left uncoated. (b) A side view,*

where objects of interest (red) are seen trapped by electric fields between the tips. (Graphics courtesy of Robert Lindner.)

Recently, we achieved the selective self-organization of spheres within a trench formed by optical lithography on a silicon wafer, using a doctor-blade-based NSL technique.[18,19] Sphere deposition can be largely suppressed by a self-assembled layer of octadecyltrichlorosilane molecules on the substrate top surface: see Figure 2(a). Using this arrangement, we can create pairs of opposing metallic tips with nanometric tip radii within the trench. Exploiting the strong field enhancement between the tips, it should be possible to localize, manipulate, and address small objects within the trench: see Figure 2(b). Future work will deal with exploiting such linearly arranged field concentrators, with further improvements of large-area 2D NSL masks, and with the in-depth characterization of selected plasmonic and catalytic nanoparticle systems.

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References:

1. H. W. Deckmann, J. H. Dunsmuir, Natural lithography, *Appl. Phys. Lett.*41, p. 377-379, 1982.
2. C. L. Haynes, R. P. Van Duyne, Nanosphere lithography: a versatile nanofabrication tool for studies of size-

dependent nanoparticle optics, *J. Phys. Chem. B*105, p. 5599-5611, 2001.

3. F. Burmeister, W. Badowsky, T. Braun, S. Wieprich, J. Boneberg, P. Leiderer, Colloid monolayer lithography—a flexible approach for nanostructuring of surfaces, *Appl. Surf. Sci.*144, p. 461-466, 1999.
4. J. K. N. Lindner, D. Bahloul-Hourlier, D. Kraus, M. Weinl, Th. Mélin, B. Stritzker, TEM characterization of Si nanowires grown by CVD on Si pre-structured by nanosphere lithography, *Mater. Sci. Semicond. Proc.*11, p. 169-174, 2008.
5. J. Pauly, J. K. N. Lindner, TEM characterization of nickel nanodot arrays on silicon formed by nanosphere lithography, *Eur. Mater. Res. Soc. Symp. Proc.*, 2012.
6. J. K. N. Lindner, C. Seider, F. Fischer, M. Weinl, B. Stritzker, Regular silicon surface patterns by local swelling induced by He implantation through nanosphere lithography masks,*Nucl. Instrum. Methods Phys. Res. B*267, p. 1394-1397, 2009.
7. F. J. C. Fischer, M. Weinl, J. K. N. Lindner, B. Stritzker, Nanoscale surface patterning of silicon using local swelling induced by He implantation through NSL-masks, *Mater. Res. Soc. Proc.*1181, 2010.
8. N. Nagy, Z. Zolnai, E. Fulop, A. Deak, I. Barsony, Tunable ion-swelling for nanopatterning of macroscopic surfaces: the role of proximity effects, *Appl. Surf. Sci.*259, p. 331-337, 2012.
9. M. C. Gwinner, E. Koroknay, L. Fu, P. Patoka, W. Kandulski, M. Giersig, H. Giessen, Periodic large-area metallic split-ring resonator metamaterial fabrication based on shadow nanosphere lithography, *Small*5, p. 400-406, 2009.
10. T. Riedl, M. Strake, W. Sievers, J. K. N. Lindner, Thermal modification of nanoscale mask openings in polystyrene sphere layers, 2013. Paper accepted at the Mater. Res. Soc. Fall Meeting in Boston, MA, 1–6 December 2013.

11. M. Manso Silván, M. Arroyo Hernández, V. Torres Costa, R. J. Martín Palma, J. M. Martínez Duart, Structured porous silicon sub-micrometer wells grown by colloidal lithography, *Europhys. Lett.*76, p. 690-695, 2006. doi:10.1209/epl/i2006-10331-2
12. D. Gogel, M. Weinl, J. K. N. Lindner, B. Stritzker, Plasma modification of nanosphere lithography masks made of polystyrene beads, *J. Optoelectron. Adv. Mater.*12, p. 740-744, 2010.
13. J. K. N. Lindner, B. Gehl, B. Stritzker, Shape modifications of self-organised colloidal silica nano-masks on silicon, *Nucl. Instrum. Methods B*242, p. 167-169, 2006.
14. J. Lindner, D. Kraus, B. Stritzker, Ion beam induced sintering of colloidal polystyrene nanomasks, *Nucl. Instrum. Methods B*257, p. 455-458, 2007.
15. R. M. Kemper, M. Weinl, Ch. Mietze, M. Häberlen, E. Tschumak, J. K. N. Lindner, K. Lischka, D. J. As, Growth of cubic GaN on nano-patterned 3C-SiC substrates, *J. Cryst. Growth*323, p. 84-87, 2011.
16. C. M. Zhou, D. Gall, Development of two-level porosity during glancing angle deposition,*J. Appl. Phys.*103, p. 014307, 2008. doi:10.1063/1.2828174
17. C. Khare, R. Fechner, J. Bauer, M. Weise, B. Rauschenbach, Glancing angle deposition of Ge nanorod arrays on Si patterned substrates, *J. Vac. Sci. Technol. A*29, p. 041503, 2011. doi:10.1116/1.3589781
18. K. Brassat, F. Assion, U. Hilleringmann, J. K. N. Lindner, Self-organization of nanospheres in trenches on silicon surfaces, *Phys. Status Solidi A*210, p. 1485-1489, 2013.doi:10.1002/pssa.201200899
19. K. Brassat, J. K. N. Lindner, A template-assisted self-organization process for the formation of a linear arrangement of pairs of metallic nanotips, 2013. Paper accepted at the Mater. Res. Soc. Fall Meeting in Boston, MA, 1–6 December 2013.