Cryogenic amplification at room temperature: the pentacene:*p*-terphenyl MASER

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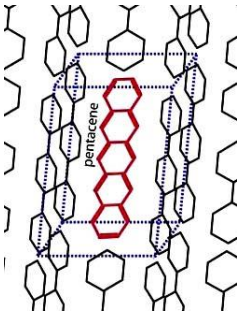
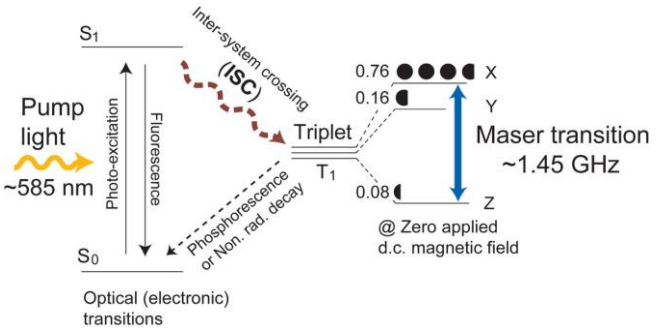
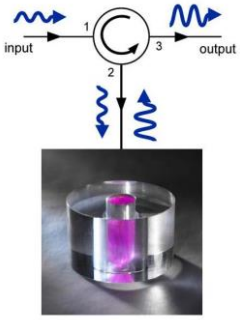
Abstract:







Masers are lasers that exploit paramagnetic transitions to amplify microwaves. Half a century ago, solid-state masers fought and lost against transistors as the signal amplifiers of choice within telecommunication equipment. Transistors worked at room temperature and offered greater signal bandwidths. Nevertheless, by dint of their completely different operating mechanism (the flipping of static spins by stimulated emission), masers offer some distinct advantages over electronic amplifiers (based on the stochastic movement of charge carriers), particularly in the making of sensitive, accurate measurements where noise and distortion matter. It is perhaps remarkable that the state-of-the-art GaAs/InP HEMT-based (M)MIC amplifiers currently being evaluated for use across the Square Kilometre Array telescope, are noisier than the ruby masers developed by NASA in the 1970s for its Voyager 1&2 missions. Niches of advantageousness for masers include more sensitive variants of EPR spectroscopy, read-out schemes for spin-based quantum computers, and embodiments of "quantum optics" at microwave and radio frequencies more generally.

Using an optical pumping mechanism based on molecular intersystem crossing (ISC), a solid-state maser was recently gotten to work at room temperature for the first time [1]. This maser needs no applied magnetic field. Its organic gain medium is a solid solution of pentacene molecules trapped as substitutional dopants within a crystal of *para*-terphenyl –a system that has been exploited over recent years in the context of dynamic nuclear polarization (DNP) [2]. Furthermore, the ISC-based pumping of photo-excited pentacene generates an initial emissive spin polarization on its lowest triplet state with a Boltzmann equivalent spin temperature of -70 mK. This fuels the pulsed multiplication of microwave photons at a noise temperature lying within a factor of a few of the quantum (shot-noise) limit set by spontaneous emission, namely 30 mK, whilst the lattice temperature of the maser gain medium remains at room-temperature. The latest progress shall be presented.

[1] "Room-temperature solid-state maser", M. Oxborrow, J. D. Breeze, N. M. Alford, *Nature* **488**, 353-356 (2012).

[2] "Room temperature hyperpolarization of nuclear spins in bulk", K. Tateishi *et al* , PNAS **111**, 7527-7530 (2014).