Statistical Study of Site Controlled InGaN Quantum Dots

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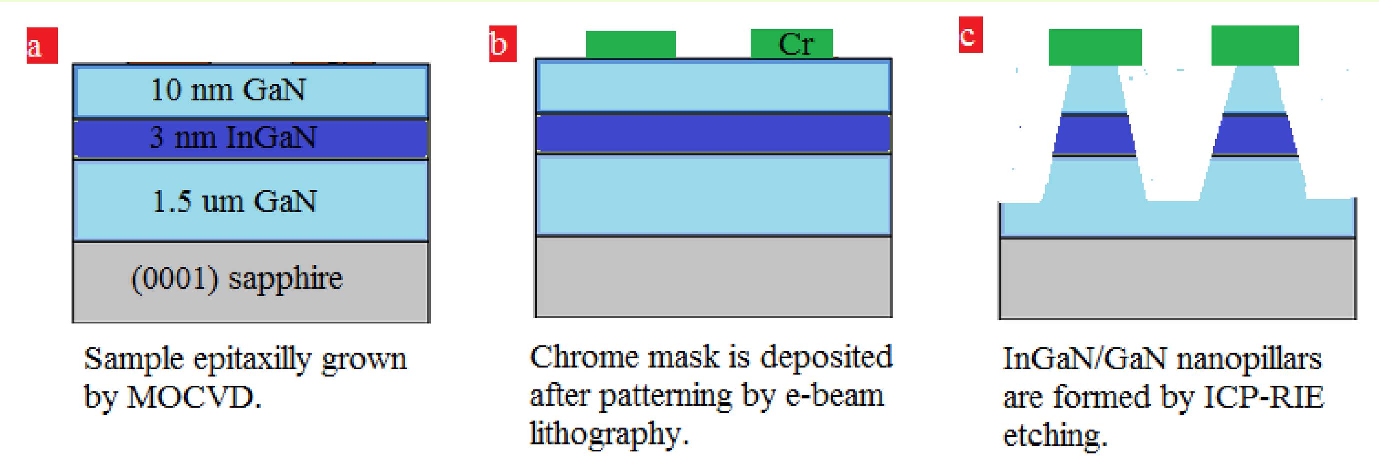
Introduction

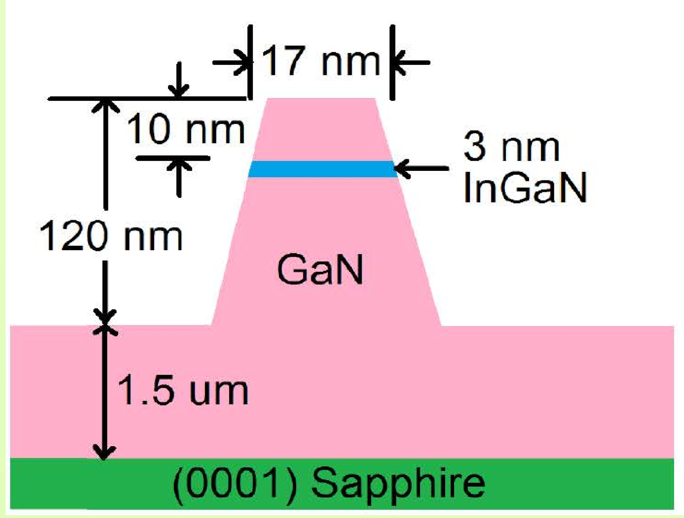
The Quantum dot (QD) is an important building block for many quantum optoelectronic devices ranging from single photon source and quantum computer qubit to QD lasers. Yet, to date most of the epitaxially grown QDs were made from III-As and III-P materials which suffer from cryogenic operation condition.

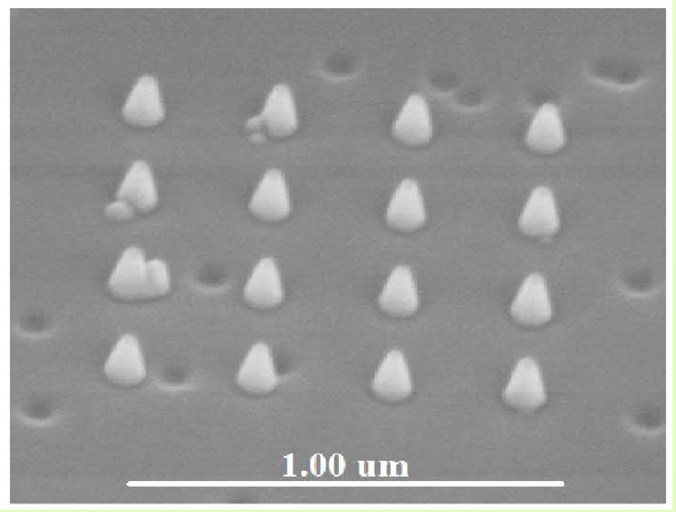
III-nitride materials have wide bandgaps and large exciton binding energies (~26 meV), and thus hold the promise for quantum optoelectronic devices that function at room temperature [1]. Most of the nitride QD studies have focused on self-assembled QDs. The random position of such QDs impedes controllable integration with microcavities for advanced quantum devices such as the QD lasers.

Here we report single photon emission from a size- and site-controlled InGaN/GaN quantum dot (QD) fabricated by plasma etching of patterned single quantum wells. Taking advantage of the site control, we carry out a detailed statistical analysis to better understand the system microscopics to guide future development towards a site controlled room temperature InGaN single photon source.

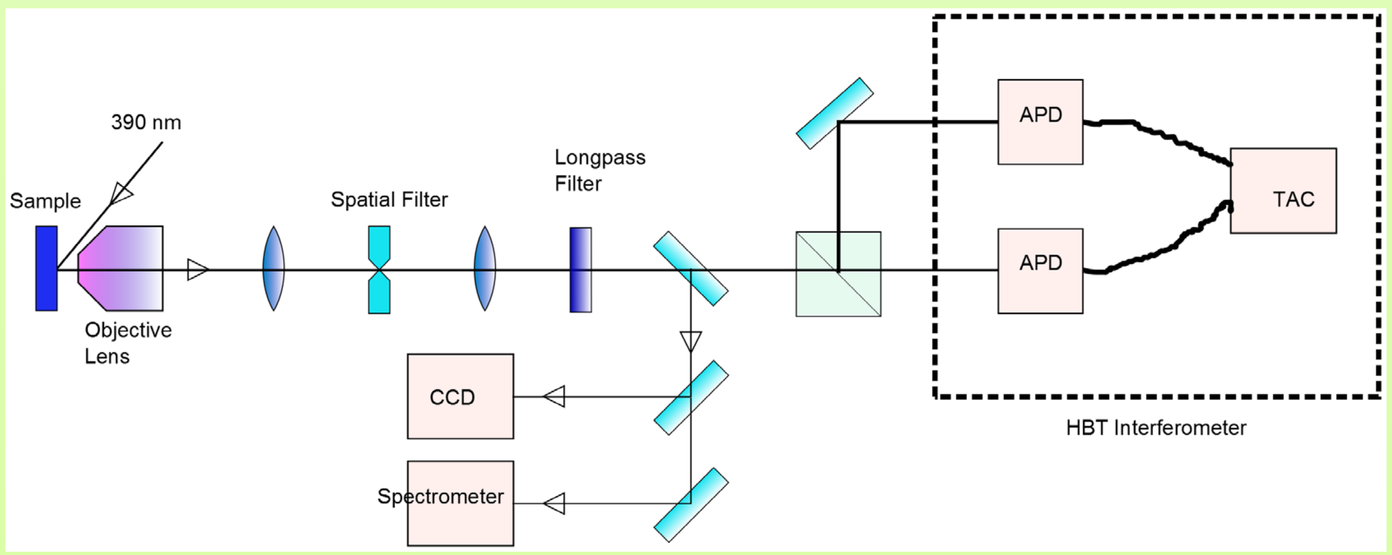
Fabrication and Sample Description





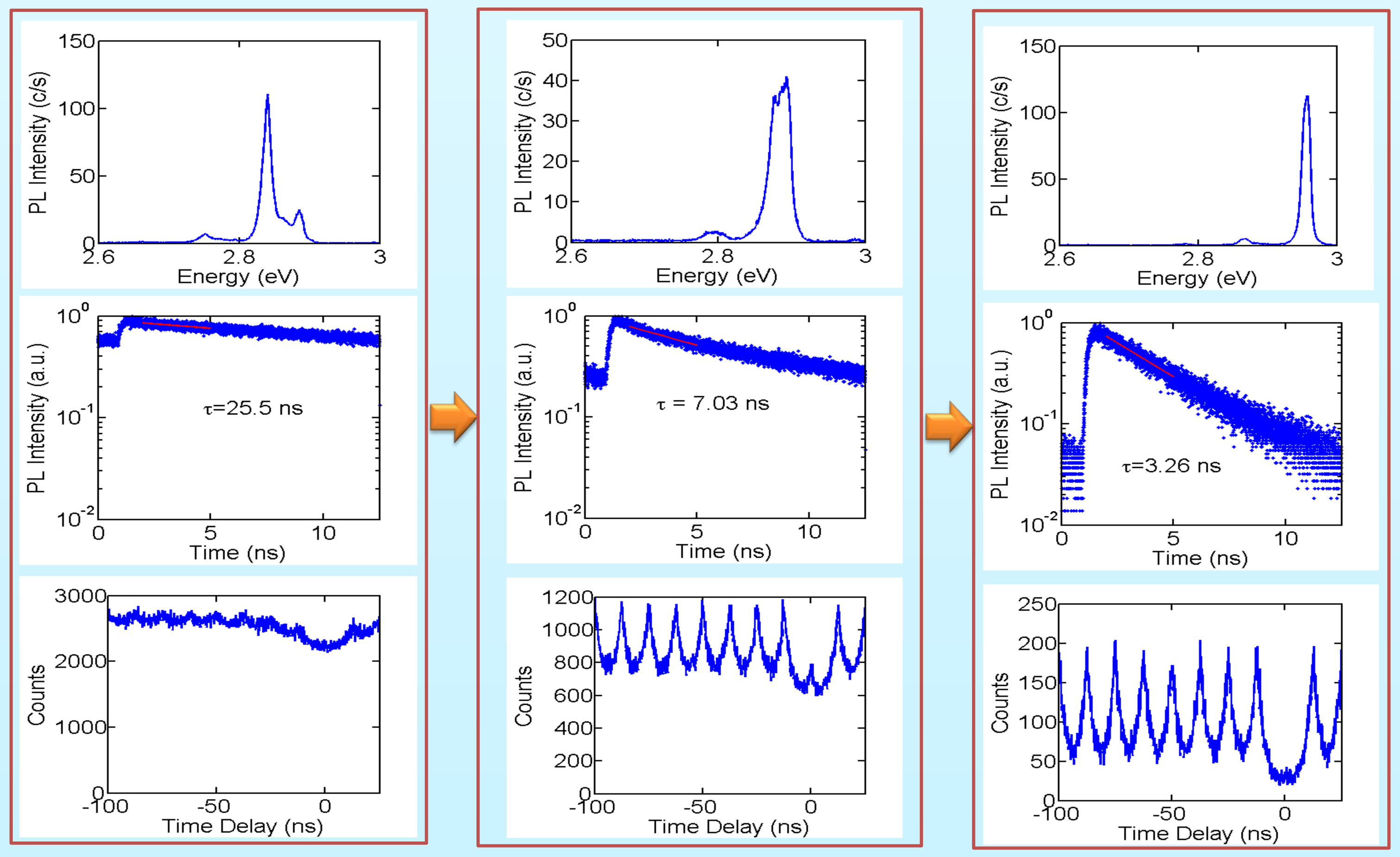


Optical Measurement Setup



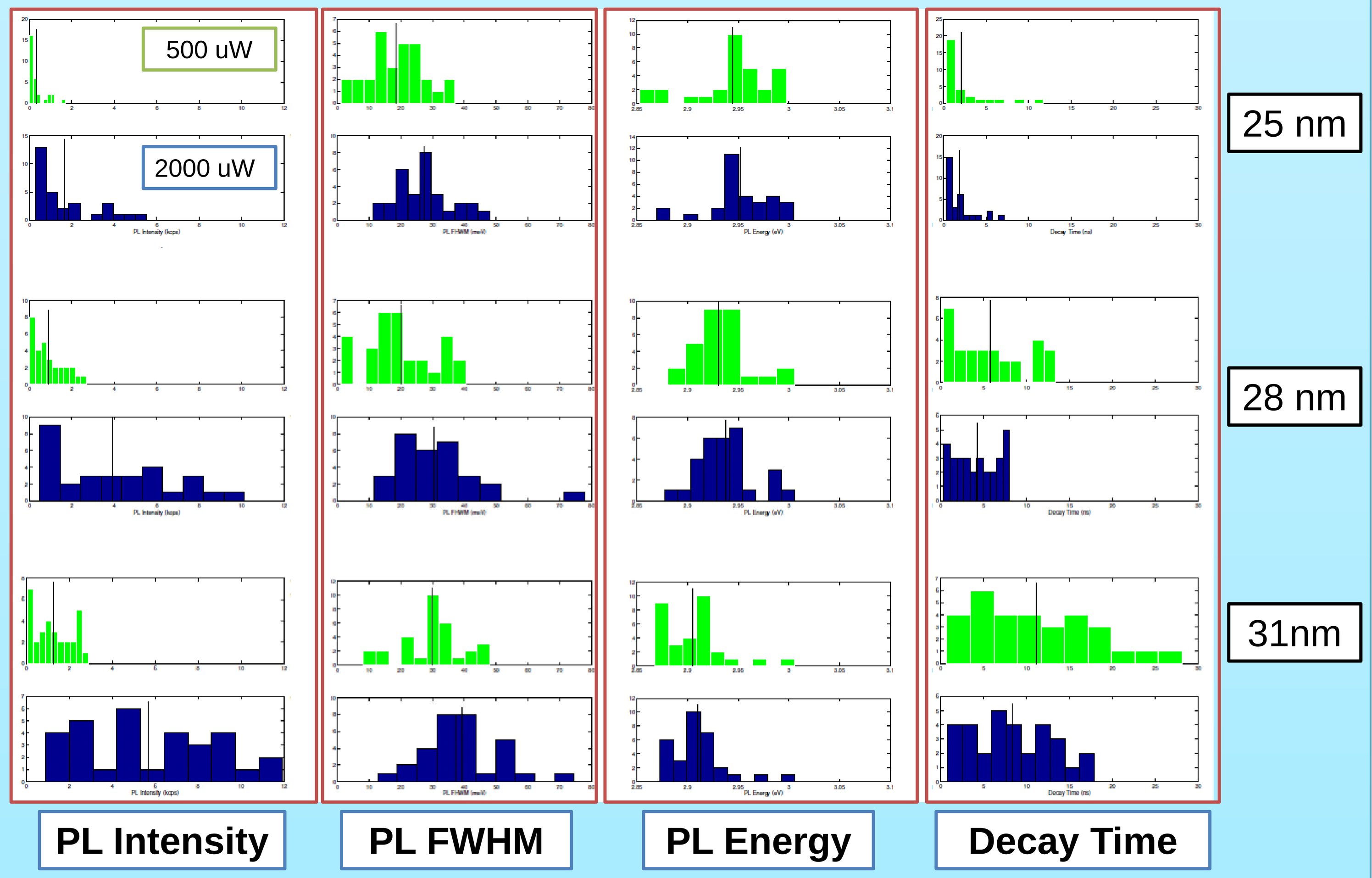
Individual QD Dynamics

Time-Integrated and Time-Resolved photoluminescence, Second Order correlation measurement



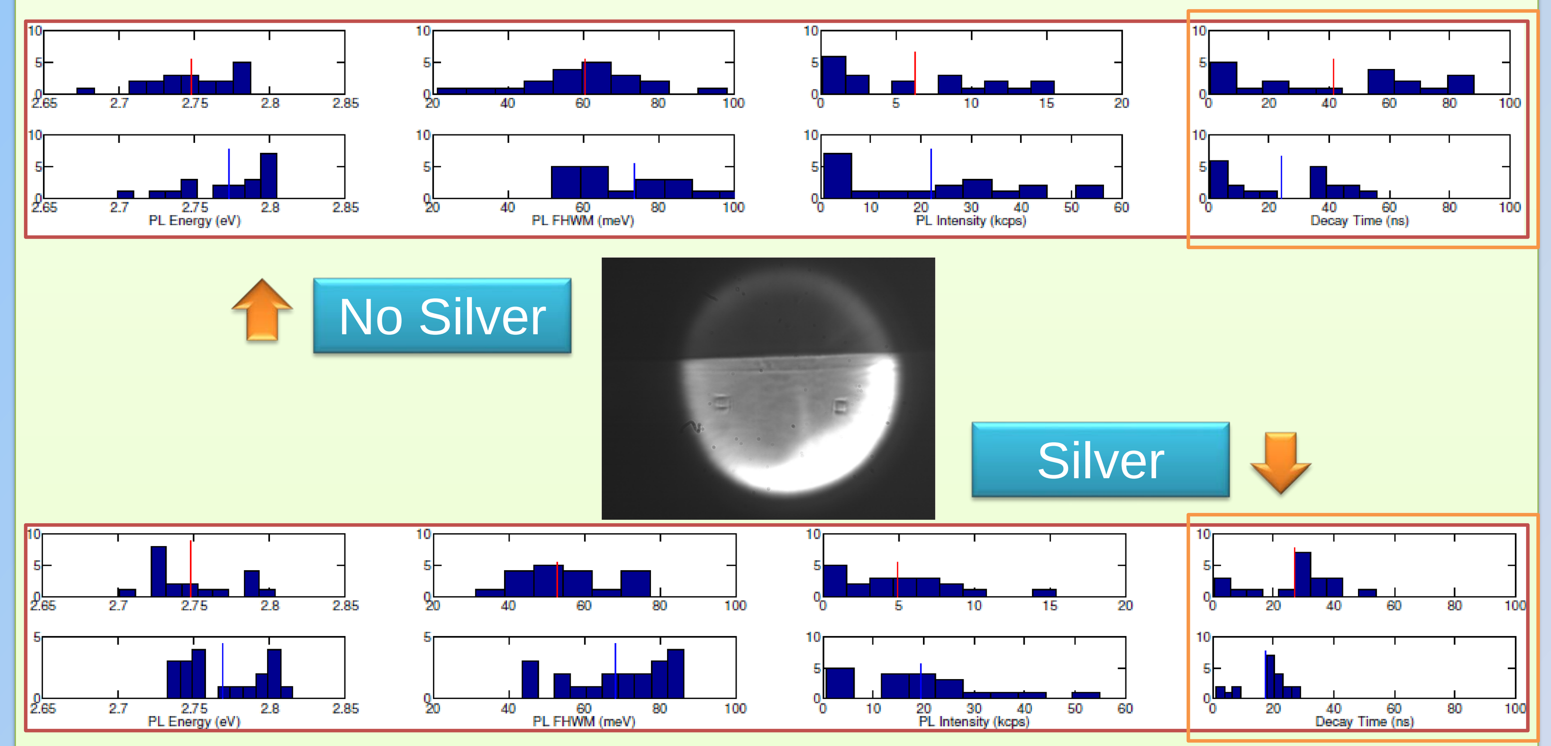
By examining the raw data of many individual dots, we can identify trends that merit further study. Here we see a correlation between dot energy, Time-resolved photoluminescence (TRPL) lifetime, and pulsed g2(0) antibunching depth.

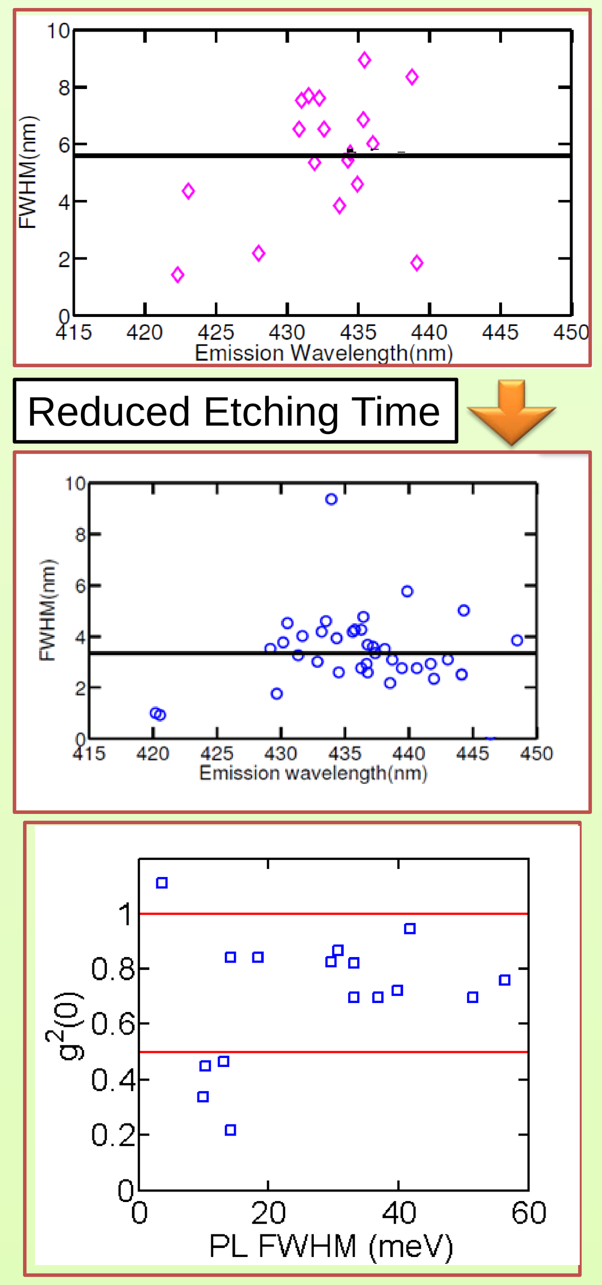
Statistical QD Properties



Dot brightness increases per unit area has superlinear size dependence. FWHM increases with dot size, PL energy decreases with increasing dot size, and larger dots have much longer TRPL decay times. A similar analysis is possible using a dense array of quantum dots, but this omits information on the distribution of individual dot properties, and can incorrectly weight the contribution from dots of varying brightness.

Improving Device Performance





We investigate the effect of adding a thin layer of silver ~20nm on top of the quantum dots. Using statistical analysis, we find an approximate 40% reduction in the TRPL lifetime of these dots, with other dot properties appearing unchanged. This has an advantage over a traditional cavity, as there is no need to position the dot with respect to any cavity and this method can alter the lifetime of many dots simultaneously.

Statistical analysis of the effect of changing various device parameters (in this case plasma etching time) allows the experimenter to have a quantitative understanding of how each fabrication step may effect device performance. Taken together with the many statistical trends this can improve understanding of the underlying physics. Here we see how changing in etching time, which effects surface quality, is correlated to changing FWHM and second order correlation measurements.

Conclusion: We demonstrate a single photon source with site controlled InGaN quantum dots. We perform a statistical study of a wide range of dot parameters, getting an accurate picture of device performance unaffected by experimental sampling bias. We find many statistically significant and reproducible trends relating different sample device parameters. We demonstrate a significant reduction in TRPL decay time from an array of dots using a thin silver film.

References:

[1] S. Kako, C. Santori, K. Hoshino, S. G¨otzinger, Y. Yamamoto, and Y. Arakawa, Nature materials 5,887 (2006).