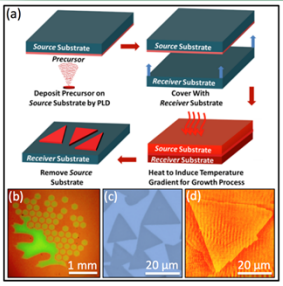
Digital Transfer Growth of Patterned 2D Metal Chalcogenides by Confined Nanoparticle Evaporation



(a) Illustration of the digital transfer growth technique. Nanoparticles deposited by PLD onto a *source* substrate are covered by a *receiver* substrate and heated in a background gas. The nanoparticles evaporate and grow 2D crystals by confined vapor transport on the receiver substrate. (b) Complex patterns of PLD-deposited nanoparticles on the source substrate can be transferred into identical patterns on the receiver substrate that are composed of triangular monolayer 2D crystals, shown in (c) optical and (d) AFM images.

Work was performed as a User Project at the Center for Nanophase Materials Sciences.

Scientific Achievement

A new method was developed to synthesize large-area 2D metal chalcogenide crystals of controlled layer number and stoichiometry in prepatterned locations by confined evaporation of laser-deposited nanoparticles.

Significance and Impact

This unique approach overcomes several processing roadblocks for the scalable growth and patterning of 2D metal chalcogenide crystals for optoelectronic and energy related applications.

Research Details

- Pulsed laser synthesized GaSe (or $MoSe_2$) nanoparticles were deposited in patterns on a *source* substrate, which were then evaporated to grow large 2D crystals of GaSe (or $MoSe_2$) on a cooler *receiver* substrate in close proximity.
- Large monolayer crystalline domains (~100 µm lateral sizes) of GaSe and $MoSe_2$ were demonstrated in the patterned locations, as well as continuous monolayer films through the deposition of additional precursor materials.
- The technique combines the advantages of pulsed laser deposition (PLD), i.e., stoichiometry transfer and digital deposition control, with the novel confined vapor transport growth from evaporated nanoparticles.

M. Mahjouri-Samani, *et. al.*, *ACS Nano* (2014). DOI: 10.1021/nn5048124

U.S. DEPARTMENT OF ENERGY | Office of Science

THE UNIVERSITY of TENNESSEE KNOXVILLE

OAK RIDGE National Laboratory

Narrative Highlight Text

A novel growth technique for the controlled synthesis of monolayer or few-layer 2D metal chalcogenide crystals that should prove useful for their scaled production for optoelectronic and energy applications, is demonstrated. The "digital transfer growth" technique uses nanoparticles as a stoichiometric precursor, which were formed and digitally deposited in a single step by pulsed laser deposition (PLD) onto a "source" substrate. A confined growth system was then formed by covering the source substrate with a "receiver" substrate. By heating the source substrate, a temperature gradient simultaneously produced a suitable temperature range for nanoparticle evaporation on the source substrate, and for the growth of 2D crystals on the receiver substrate by vapor transport. This simple approach overcomes issues encountered during other growth approaches, such as evaporative losses of precursors, non-uniformity of deposits due to boundary layer diffusion, and lack of control over layer number. Moreover, since diffusion is limited, patterns could be transferred directly from source to receiver substrate. The technique is promising for growth of a wide variety of 2D metal chalcogenides and should be scalable for industrial production.

Reference

"Digital Transfer Growth of Patterned 2D Metal Chalcogenides by Confined Nanoparticle Evaporation"
M. Mahjouri-Samani[1], M. Tian[3], K. Wang[1], A. Boulesbaa[1], C. M. Rouleau[1], A. A. Puretzky[1], G. Eres[2], M. A. McGuire[2], B. R. Srijanto[1], K. Xiao[1], G. Duscher[2, 3], and D. B. Geohegan[1]
[1]Center for Nanophase Materials Science, ORNL
[2]Materials Science and Technology Division, ORNL
[3]Department of Materials Science and Engineering, University of Tennessee
ACS Nano (2014). DOI: 10.1021/nn5048124.

Acknowledgement

Synthesis science including *in situ* PLD diagnostics, TEM analysis, SEM and AFM studies, bulk crystal growth, and transfer technique development (MMS, KW, GE, DBG, CMR, AAP, MAM, GD, MT) was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences (BES), Materials Sciences and Engineering Division and performed in part as a user project at the Center for Nanophase Materials Sciences, which is a DOE Office of Science User Facility. Characterization science at CNMS including optical characterization and lithography techniques (AB, KX, BRS, AAP, CMR) was supported by the Scientific User Facilities Division, BES.