# Direct growth of germanene at the interface between a van der Waals material and Ag(111)

**Seiya Suzuki**[1]
Takuya Iwasaki[2], K. Kanishka H. De Silva[3], Shigeru Suehara[2], Kenji Watanabe[4], Takashi Taniguchi[1,2], Satoshi Moriyama[5], Masamichi Yoshimura[3], Takashi Aizawa[2], Tomonobu Nakayama[1,2,6]
[1]*International Center for Young Scientists (ICYS), National Institute for Materials Science (NIMS), 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan*
[2]*International Center for Materials Nanoarchitectonics (MANA), NIMS, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan*
[3]*Toyota Technological Institute, 2-12-1 Hisakata, Nagoya, Aichi 468-8511, Japan*
[4]*Research Center for Functional Materials, NIMS, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan.*
[5]*School of Engineering, Tokyo Denki University, 5 Senju-Asahi-cho, Adachi-ku, Tokyo 120-8551, Japan.*
[6]*Graduate School of Pure and Applied Sciences, University of Tsukuba, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan*
SUZUKI.Seiya@nims.go.jp

Abstract

Germanene is a two-dimensional (2D) allotrope of germanium (Ge), with a honeycomb lattice similar to that of graphene. Theoretical calculations have predicted that germanene is a 2D topological insulator with a moderate spin-orbit bandgap (~24 meV), which is desirable for next-generation electronic devices. The growth of germanene has been reported on single crystal metal surfaces, such as Au, Al, and Ag in ultra-high vacuum [1]. However, there are no reports of electronic devices using germanene. One of the main reasons for this is the chemical instability of germanene, which hinders its device fabrication.

To overcome the instability of germanene, we present the direct growth of germanene at the graphene/Ag(111) and hexagonal boron nitride (h-BN)/Ag(111) interfaces [2]. As shown in Fig. 1(a), our growth process consists of transfer cap layer (graphene or h-BN) on Ag(111)/Ge(111) followed by heating in $N_2$ at ambient pressure. The grown germanene is stable in air, so that Raman spectra of germanene can be recorded using an ordinally *ex situ* Raman microscope. Figure 1(b) shows the Raman spectra of the samples after heating up to 550 ºC. With density functional theory calculations, we assigned the Raman peaks at 155 and 255 $cm^{-1}$ as the out-of-plane and in-plane vibrational modes of germanene, respectively. We also found that van der Waals materials are the key to germanene growth since germanene was not grown with $Al_2O_3$ cap layer (Fig.1(c)).

## REFERENCES

[1] J. Yuhara *et. al.*, ACS Nano 12, 11 (2018) 11632.
[2] S. Suzuki *et al.*, Adv. Funct. Mater. 31, 5 (2021) 2007038.

## FIGURES

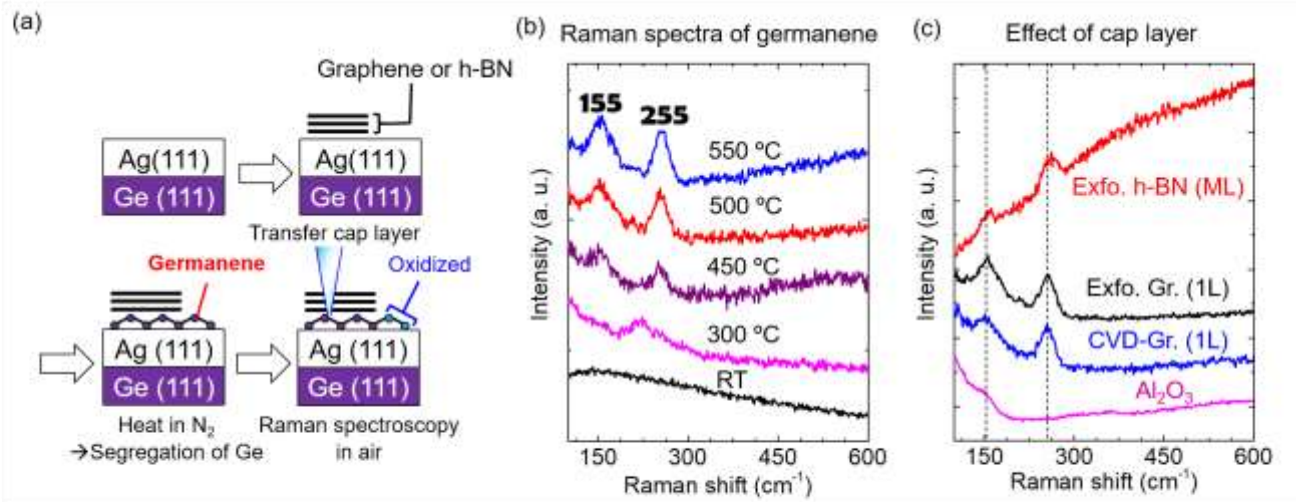


**Figure 1:** (a) Schematic of the present germanene growth (b) Raman spectra of samples after annealing at different temperatures (c) Raman spectra of germanene with different cap layers such as exfoliated (Exfo.) h-BN multilayer (ML) and chemical vapor deposited (CVD) monolayer (1L) graphene.