

# Cryogenic photovoltage nanoscopy in twisted multilayer graphene.

---

## **Petr Stepanov**

Niels C. H. Hesp

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

[nielshesp@me.com](mailto:nielshesp@me.com)

Sergi Battle-Porro

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

[Sergi.Battle@icfo.eu](mailto:Sergi.Battle@icfo.eu)

Roshan Krishna Kumar

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

[Roshan.KrishnaKumar@icfo.eu](mailto:Roshan.KrishnaKumar@icfo.eu)

Hitesh Agarwal

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

[hitesh.agarwal@icfo.eu](mailto:hitesh.agarwal@icfo.eu)

David Barcons-Ruiz

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

[David.Barcons@icfo.eu](mailto:David.Barcons@icfo.eu)

Hanan Herzig Sheinflux

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

[lightmatterinteractions@gmail.com](mailto:lightmatterinteractions@gmail.com)

Kenji Watanabe

Research Center for Functional Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

[WATANABE.Kenji.AML@nims.go.jp](mailto:WATANABE.Kenji.AML@nims.go.jp)

Takashi Taniguchi

International Center for Materials Nanoarchitectonics. National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan.

[TANIGUCHI.Takashi@nims.go.jp](mailto:TANIGUCHI.Takashi@nims.go.jp)

Frank H.L. Koppens

ICFO, Av. Carl Friedrich Gauss 3, Castelldefels, Barcelona, Spain 08860

ICREA-Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

[Frank.koppens@icfo.eu](mailto:Frank.koppens@icfo.eu)

---

Magic angle twisted bilayer graphene has been realized as a new platform to study strongly correlated quantum states of matter such as superconductors, correlated insulators and topological orders hosted by its native flat bands. Recent observations of anomalous Hall effect in MATBG revealed a non-zero Berry-curvature-induced orbital ferromagnetism and has been followed by extensive experimental and theoretical studies of its origin. Initial electronic transport studies demonstrated anomalous Hall effect at  $\nu=+3$  electrons per moiré unit cell in the samples aligned with the adjacent insulating hBN layer, which breaks MATBG moiré inversion symmetry thus assisting in opening non-trivial insulating gaps with finite Chern numbers. Here we report on photovoltage scanning near-field imaging at cryogenic temperatures (10 K) of a MATBG device structurally aligned with hBN layer. We reveal a complex pattern of quasi-local photovoltage fringes attributed to the second-order superlattice (supermoiré) potential modulated through the sample bulk. We assume that predominantly the photocurrent originates from PV generation mechanisms induced by the proximity of a hot spot formed on the metallic atomic force microscopy tip radiated by mid-infrared photons. Strikingly, we find a clear change of the PTE fringes' real-space orientation when the sample doping changes between the valence and conductance flat bands which may signal a nematic ordered state in a highly doping-dependent low-energy spectrum of MATBG. Our observation sheds a new light on the microscopic mechanisms of the inversion symmetry breaking on a mesoscale lengthscale.