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Formation and Characterization of 2D Metal Carbides for EM Shielding Applications: Experimental and First Principles Computational Study

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ANKARA, ,
TUR

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Final Technical Report

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14. ABSTRACT
--Growth of Mo2C crystals was studied through chemical vapor deposition on copper substrates. The effects of impurities, Cu substrate thickness, and graphene presence on the morphology and crystal quality were investigated. Two growth regions were identified: directly on the copper surface and on graphene-covered areas. Mo2C crystals formed on graphene exhibited enhanced properties attributed to graphene's role as a diffusion barrier for Mo atoms. Additionally, the formation of a graphene/ Mo2C /graphene sandwich structure was observed, showing promise for electronic applications.
An alternative approach to Mo2C crystal growth using liquid indium as a substrate was studied. The team demonstrated the suitability of In as an suitable substrate for the growth of Mo2C crystals through the CVD (Chemical Vapor Deposition) method.
--An investigation into the growth mechanism of Mo2C crystals on In utilizing the CVD technique has been undertaken. The proposed model indicates an inversely proportional relationship between the vertical growth of Mo2C crystals and the thickness of the In substrate. This conceptual framework has been validated through AFM investigations.
--Nucleation and Growth of Graphene/ Mo2C Heterostructures on Cu through CVD study has revealed that the thickness and morphology of Mo2C crystals exhibit variability based on their growth location on the Cu surface. This variation is attributed to the differing diffusion distances traveled by Mo species. The underlying pressure conditions play a pivotal role in influencing the nucleation and growth mechanisms not only for graphene but also for Mo2C.
Besides the CVD studies, the team also performed studies on the formation of Mo2C flakes through wet etching of MAX Phase (Mo2CSnC), which in this case called MXenes. Mo2CTX, derived primarily from the Mo2Ga2C MAX phase, presents noteworthy theoretical electrochemical, thermoelectric properties, and chemical stability.
--Optical Properties of semiconductor MXene layers studies demonstrated a significant increase in the electronic band gap of the monolayer models when the GW correction is applied, in comparison to the LDA values. Utilizing the QP energies and DFT wave functions that have been corrected by GW, we proceed to address the BSE to explore both direct and indirect excitons within these monolayers. It is evident that the absorption spectra of the monolayer models experience a pronounced redshift due to the interaction between electrons and holes, resulting from the substantial binding energy of the excitons. Our observations reveal that the binding energies of the indirect excitons are generally lower than those of the direct excitons. Despite this, the indirect excitons still remain the lowest-energy excitations in the absorption spectra of monolayer models with indirect band gaps.
--In collaboration with the team behind the Yambo code (https://www.yambo-code.eu), the research established a framework to incorporate intraband optical transition computations into our initial-principles investigation of metallic architectures. Our findings suggest that factoring in the Drude correction at the GW level (screening level) exerts a notable impact on the behavior of twodimensional systems. Therefore, its incorporation is essential for a precise and comprehensive assessment of the optical traits of metallic layers.

15. SUBJECT TERMS

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PI	Assoc. Prof. Z. Goknur Buke (TOBB ETU)
Co-PI	Prof. Cem Sevik (Eskisehir Technical Uni.)
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Undergrad. Students	8 Undergrad Students (Derya Karadeniz, Asudenur Türkoğlu, Tarık Can Türkoğlu, Deniz Çakır, Su Genelioğlu, Murat Demirel, Eren Atlı, Erkin Köseoğlu, Elif Ergin)

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Summary of the Key Results

- We investigated the chemical vapor deposition (CVD) synthesis of Mo_2C/graphene heterostructures on a partially wetted liquid copper surface, studied the morphology of resulting phases using electron and optical microscopy, Raman Spectroscopy XRD and determined the rate-limiting step for the growth of Mo_2C.
- The morphology of the Mo_2C crystals varied from the center to the edge of the copper substrate because of the change in the Mo diffusion pathways owing to the variation in the thickness of the Cu substrate. Thin, hexagonal-shaped crystals of Mo_2C were found in the central region,where Cu is the thickest.
- In addition, the growth pressure substantially affects the nucleation and growth kinetics of both Mo_2C and graphene. At high pressures (750 Torr), the graphene layer fully covered the Cu surface and Mo_2C crystals formed with a regular shape, while at low pressures (5 Torr), the nucleation of both domains was suppressed, leading to the evolution of Mo_2C crystals with irregular shapes.
- Furthermore, CVD of Mo_2C has been investigated both theoretically and experimentally for the framework consisting of condensed matter of Mo-, Cu-, Graphene-, Mo_2C layers in the presence of CH_4, H_2 gases.
- Besides the CVD studies, we have also performed studies on the formation of Mo_2C flakes through wet etching, which in this case called MXenes. MXenes are the novel two-dimensional metal carbides or nitrides derived from their MAX phases. Within that context, with the aim of decreasing process duration and usage of hazardous acids like HF, the fluoride salts are mixed with hydrochloric acid to obtain in-situ hydrofluoric acid, and two different reaction temperatures for the hydrothermal etching process is studied for 24 hours (5-7 days for HCl). The synthesized MXenes are characterized using SEM and EDS for investigating morphology and chemical composition, and XRD for structural analysis. After studying the process parameters, such as temperature and etchant type on the synthesis of Mo_2CTx powders, Mo_2CTx powders are hand-mixed with epoxy resin with differing weight percentages to produce epoxy/ Mo_2CTx composites and to study their electromagnetic interference shielding effectiveness performance.
- We investigated optical properties of the MXene via first principles simulations. We have performed high-level computational test to figure out the effect of GW level techniques to investigate optical properties of MXenes. The paper is published in Physical Review B.

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- We have performed high-level computational tests to figure out the effect of GW-level techniques to investigate the optical properties of MXene crystals. We predicted the strong influence of GW-level corrections on the optical properties of layered MXenes. However, our systematic tests also show that the effect is limited in Bulk structure form with vdW stackings of individual MXene layers.
- We formulated an approach to apply Drude correction to optical property calculations of Metallic MXene structures. Now we have a complete picture to compare the optical properties of different MXene layers.
- Using the approach we designed, we work on the classification of Bulk MXene materials for efficient Electro Magnetic Shielding applications.
- Parallel with the project objective, "To develop fundamental materials understanding of the Mo2C system", we investigate the potential of MXenes as superconducting materials and we predicted interesting futures, parts of which agree very well with experimental findings. Three papers are published in RSC, Nanoscale.
- Our research group gained a hands-on experience in the first-principles characterization of optical properties and exciton dynamics in 2D materials. Using this high-level experience heterobilayer transition metal dichalcogenides were investigated. The paper is published in ACS, Nano Letters.
- An interatomic potential for Mo_2C crystal which provides very good agreement with first principles simulations for mechanical properties of this crystal has been developed and shared with Dr. Martini's research group. The paper is published in AIP Advances.

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CVD Synthesis and Characterization of Thin Mo_2C Crystals

Growth of Mo2C crystals was studied through chemical vapor deposition on copper substrates. The effects of impurities, Cu substrate thickness, and graphene presence on the morphology and crystal quality were investigated. Two growth regions were identified: directly on the copper surface and on graphene-covered areas. Mo_2C crystals formed on graphene exhibited enhanced properties attributed to graphene's role as a diffusion barrier for Mo atoms. Additionally, the formation of a graphene/ Mo_2C /graphene sandwich structure was observed, showing promise for electronic applications.

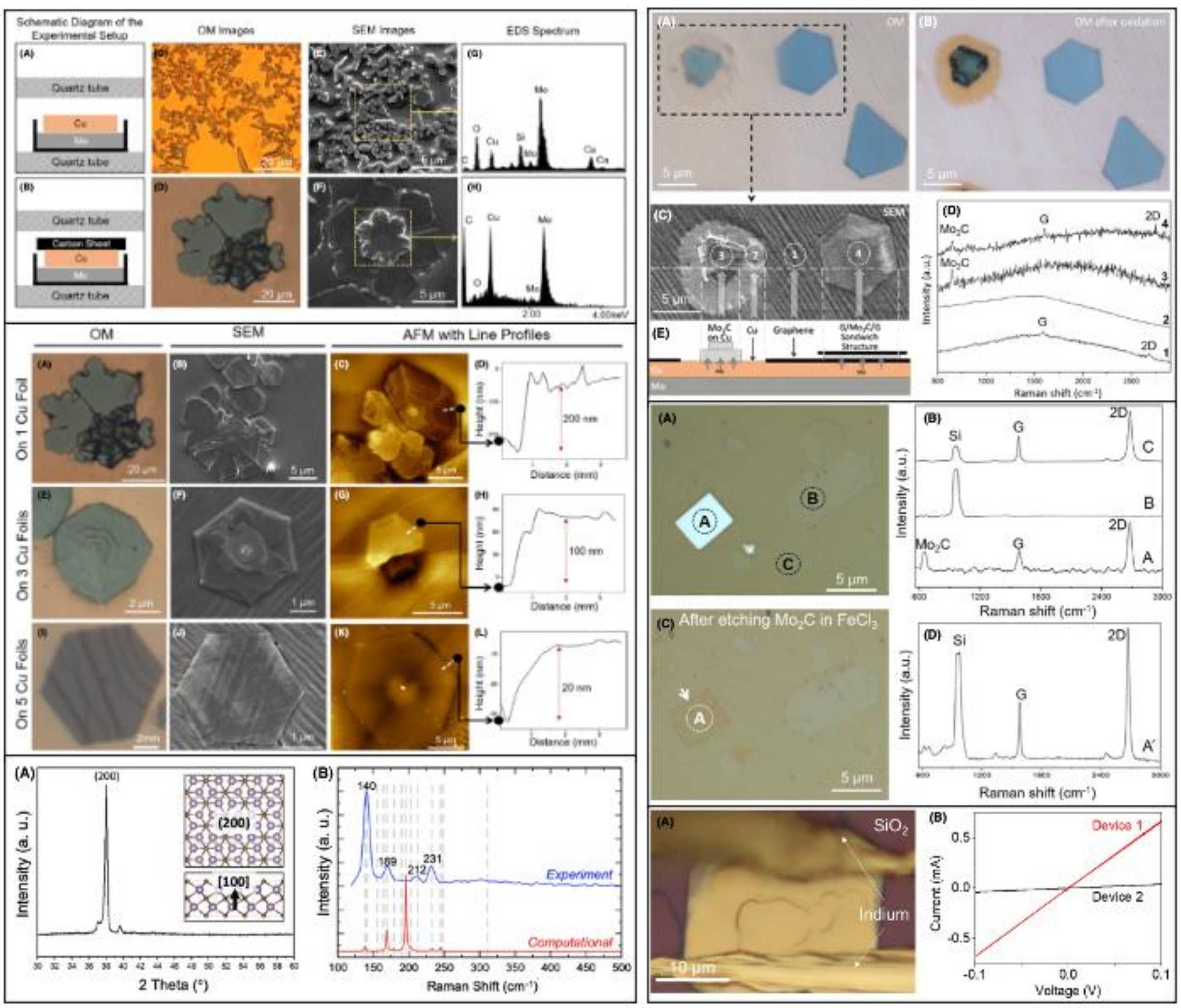

Fig. 1: Schematic Overview of the Study on CVD Synthesis and Characterization of Thin Mo2C Crystals [F. Turker, O.R. Caylan, N. Mehmood, Talip S. Kasirga, C. Sevik, G. Buke, "CVD Synthesis and Characterization of Thin Mo_2C *Crystals", JACerS, 103(10), Sept 2020.]*

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It was shown that Si atoms coming from the quartz tube affect the nucleation and growth behavior of Mo2C, hence to form thin crystals with large lateral size, the surface of the sample should be covered and kept from Si deposition. In the CVD growth of Mo2C, Cu layer acts like a valve, controlling the Mo supply for the formation of 2D Mo2C crystals. Our studies also confirmed that to decrease the thickness and to control the shape of the crystals further, the supply of the Mo atoms can be decreased by increasing the Cu layer thickness. During the growth of Mo2C crystals, due to the CH4 flow at high temperature, graphene may form at the surface simultaneously. The graphene formation is critical, because it acts as an additional diffusion barrier which may promote the formation of thinner Mo2C crystals. In the light of detailed characterization studies, we showed that Mo2C crystals, which have orthorhombic phase growing along the [100] direction, may form on two different regions: on Cu surface or on graphene. Our studies also indicated that the Mo2C crystals that form on graphene are thinner and less defective compared to the ones formed on the Cu surface. This was attributed to the presence of graphene which acts as an additional diffusion barrier for Mo atoms coming from the bulk of copper. Furthermore, we showed that Mo2C formed on graphene was also covered with graphene forming graphene/Mo2C/graphene sandwich structure. To our best knowledge direct growth of graphene/Mo2C/graphene sandwich structure is shown for the first time through this method and this heterostructure may be interesting for advanced electronic applications.

Low-Temperature Synthesis and Growth Model of Thin Mo_2C Crystals on Indium

An alternative approach to Mo2C crystal growth using liquid indium as a substrate was studied. We have demonstrated the suitability of In as an suitable substrate for the growth of Mo2C crystals through the CVD (Chemical Vapor Deposition) method. This choice is particularly advantageous due to its capacity to facilitate the formation of high quality, expansive, and thin Mo2C crystals. Notably, this growth process can be achieved at significantly lower temperatures (1000 °C) compared to the usage of copper (1085 °C). Additionally, the ease of etching of In further simplifies the subsequent transfer procedures.

Our comprehensive characterization endeavors have unveiled that these Mo2C crystals, possessing a hexagonal shape and existing in an orthorhombic state, predominantly develop along the [200] crystallographic direction. This growth phenomenon is observed beneath an amorphous carbon thin film. It's noteworthy that Mo2C crystals cultivated beneath this carbon thin film exhibit dimensions that are relatively smaller and thinner in comparison to those originating directly on the bare In surface, aligning with our expectations.

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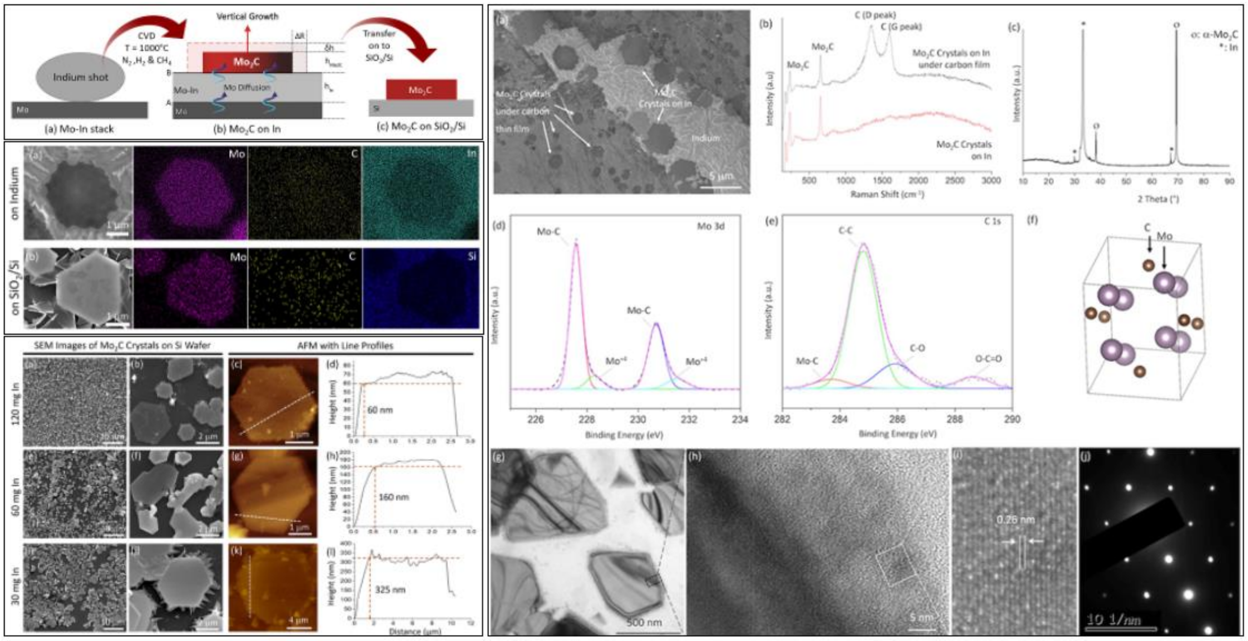

Fig. 2. Summary of the study on Low-Temperature Synthesis and Growth Model of Thin Mo2C Crystals on Indium [O. R. Caylan, G. Buke, "Low-temperature synthesis and growth model of thin Mo2C crystals on indium", Scientific Reports, 11 (1), April 2021.]

An investigation into the growth mechanism of Mo2C crystals on In utilizing the CVD technique has been undertaken. Our proposed model indicates an inversely proportional relationship between the vertical growth of Mo2C crystals and the thickness of the In substrate. This conceptual framework has been validated through AFM investigations.

While the potential for lowering the synthesis temperature exists through further optimization, our research underscores the multifaceted nature of the synthesis process. It's crucial to recognize that the melting point of the catalyst material (In) is just one aspect of consideration. Equally vital are factors such as catalyst wetting, Mo diffusivity within the catalyst (linked to catalyst viscosity), and the decomposition of hydrocarbon gas. When selecting the catalyst material and determining the appropriate temperature regime, all these aspects must be harmonized for a successful outcome.

Nucleation and Growth of Graphene/ Mo_2C Heterostructures on Cu through CVD

Our study has revealed that the thickness and morphology of Mo2C crystals exhibit variability based on their growth location on the Cu surface. This variation is attributed to the differing diffusion distances traveled by Mo species. The underlying pressure conditions play a pivotal role in influencing the nucleation and growth mechanisms not only for graphene but also for Mo2C. At lower pressures (5 Torr), the graphene film displays a discontinuous nature, with Mo2C crystals exhibiting limited nucleation. In stark contrast, under elevated pressures (750 Torr), graphene domains amalgamate, leading to a high density of nucleated Mo2C crystals. This latter scenario is of paramount importance, as the continuous graphene structure facilitates the formation of thinner and less defective Mo2C crystals.

The energy for the growth of α-Mo2C on graphene has been quantified, yielding an apparent activation energy value of 3.76 ± 0.3 eV. Speculatively, the rate-limiting step involves the diffusion of Mo towards the Cu surface via exposed Cu areas or defects in the graphene layer.

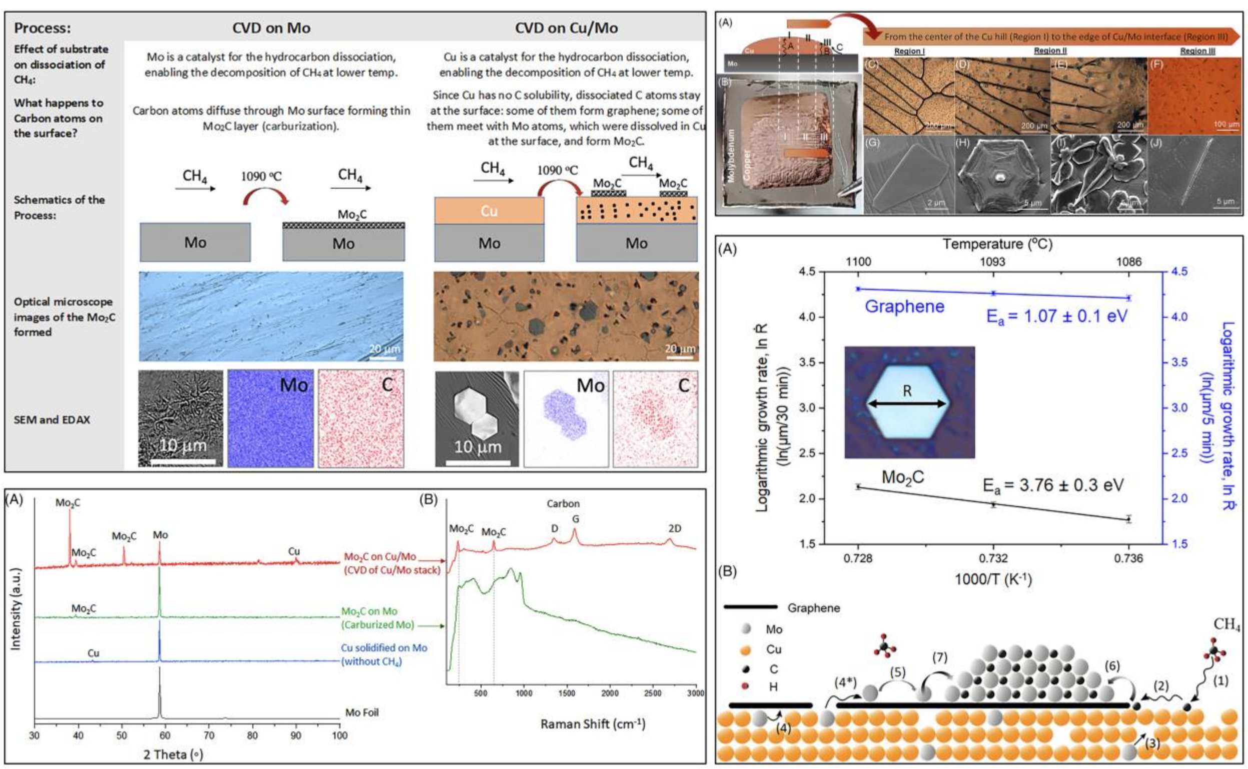

Fig. 3: Schematic Overview of the Study on Nucleation and Growth of Graphene/ Mo_2C Heterostructures on Cu through CVD [F. Turker, O.R. Caylan, G. Buke, "Nucleation and Growth of Graphene/Mo2C Heterostructures on Cu through CVD", Journal of the American Ceramic Society, October 2021]

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The insights garnered from this investigation contribute significantly to our comprehension of the fundamental aspects governing crystal growth. Furthermore, the findings hold promise for the fabrication of expansive graphene/Mo2C heterostructures with implications for diverse technological applications, including superconductors.

Synthesis and Charaterization of Mo_2CSnC MAX Phase and Mo_2C MXene

Besides the CVD studies, we have also performed studies on the formation of Mo_2C flakes through wet etching of MAX Phase (Mo_2CSnC), which in this case called MXenes. Mo2CTX, derived primarily from the Mo2Ga2C MAX phase, presents noteworthy theoretical electrochemical, thermoelectric properties, and chemical stability. Nevertheless, the protracted synthesis duration attributed to the robust Mo-Ga atomic bonding has posed a significant challenge. To address this, researchers have employed hydrothermal etching, substantially reducing the synthesis timeline. To mitigate the hazards associated with hydrofluoric acid, investigations into hydrothermal conditions using alternative etchants, including hydrochloric acid, have been conducted.

This part of the study focused on the pressureless synthesis of Mo2SnC, investigating parameters like tin content and starting powders. Additionally, it delves into the hydrothermal etching process of Mo2Ga2C for Mo2CTX production, exploring various fluoride salts, such as LiF, BaF2, MgF2, MnF4, and even no salt.

The outcomes of this study unveil several crucial insights. The synthesis of Mo2CTX utilizing MgF2, BaF2, and MnF4 salts is a novel contribution. Among the different combinations, LiF + HCl emerges as particularly promising due to the heightened water solubility of LiF, while BaF2 facilitates the retention of a higher Ga content post etching. Moreover, this study marks the first instance of investigating the electromagnetic interference (EMI) shielding properties of Mo2CTX/epoxy composites. Although only marginal enhancements were observed, the epoxy matrix exhibited limited efficiency. Unfortunately, attempts to measure conductivity from epoxy composites were unsuccessful, prompting the utilization of polyvinyl alcohol (PVA) as a binder to yield green products. However, post-sintering, the structural integrity of the pellet could not be preserved. This study was presented as poster at MRS 2021 Fall Meeting (Boston) and received MXene Symp. Best Poster Award.

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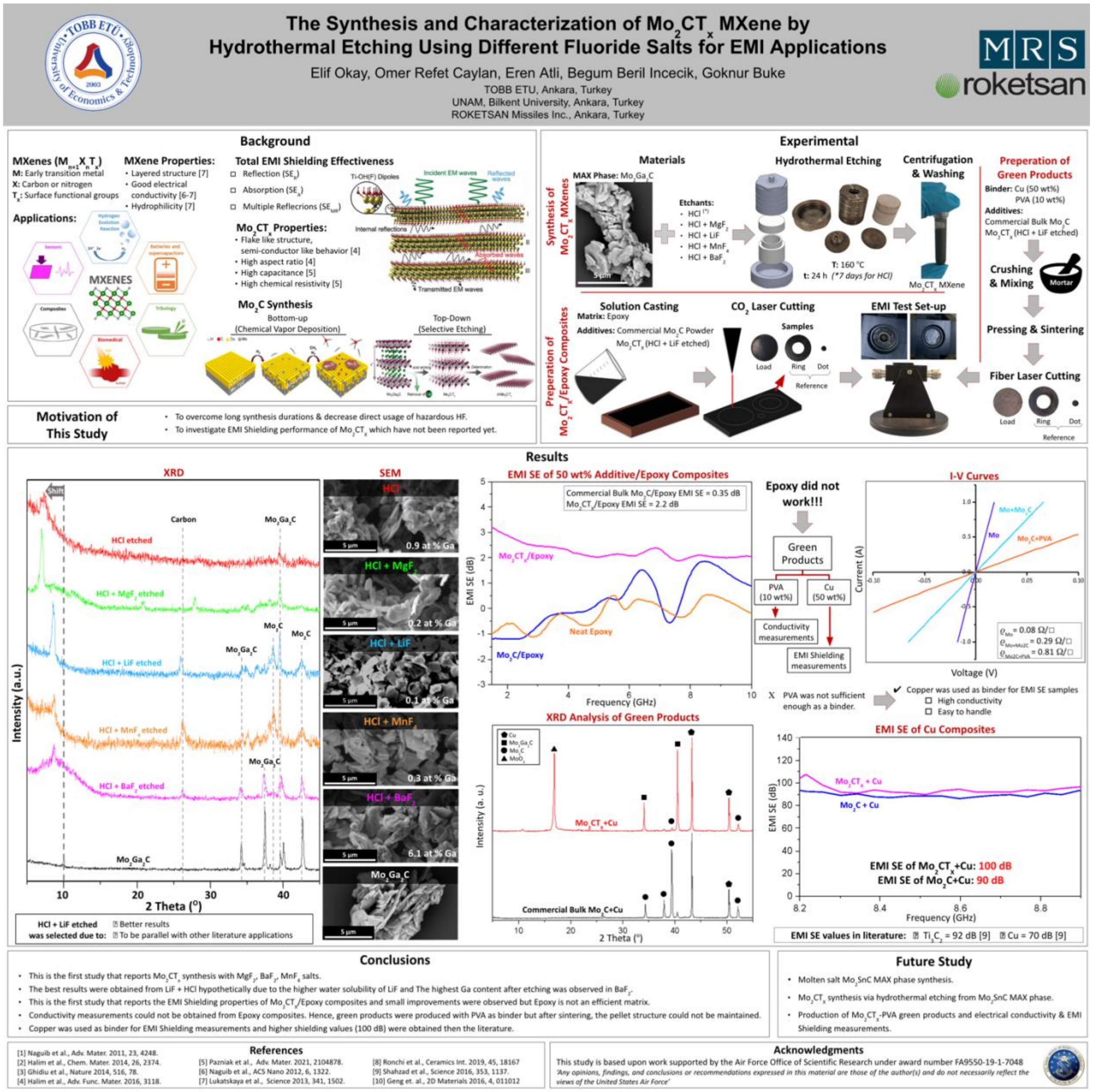

Fig. 4. The poster summarizing the study performed on Synthesis and Charaterization of Mo2CSnC MAX Phase and Mo2C MXene. This study was presented as poster at MRS 2022 Fall Meeting (Boston) and received MXene Symp. Best Poster Award.

Optical Properties of semiconductor MXene layers

We demonstrate a significant increase in the electronic band gap of the monolayer models when the GW correction is applied, in comparison to the LDA values. Utilizing the QP energies and DFT wave functions that have been corrected by GW, we proceed to address the BSE to explore both direct and indirect excitons within these monolayers. It is evident that the absorption spectra of the monolayer models experience a pronounced redshift due to the interaction between electrons and holes, resulting from the substantial binding energy of the excitons. Our observations reveal that the binding energies of the indirect excitons are generally lower than those of the direct excitons. Despite this, the indirect excitons still remain the lowest-energy excitations in the absorption spectra of monolayer models with indirect band gaps.

Our analysis indicates that although some of these excitons exhibit strong absorption in the visible region, they predominantly function as infrared emitters. This suggests the potential utilization of these excitons in applications such as infrared lasers and medical technologies. The outcomes of our study underscore the significance of adjusting the optical and electronic properties of O-terminated monolayer models through surface termination. Furthermore, the inclusion of many-body effects is essential for accurately predicting the electronic and optical characteristics of 2D MXenes in a broader context.

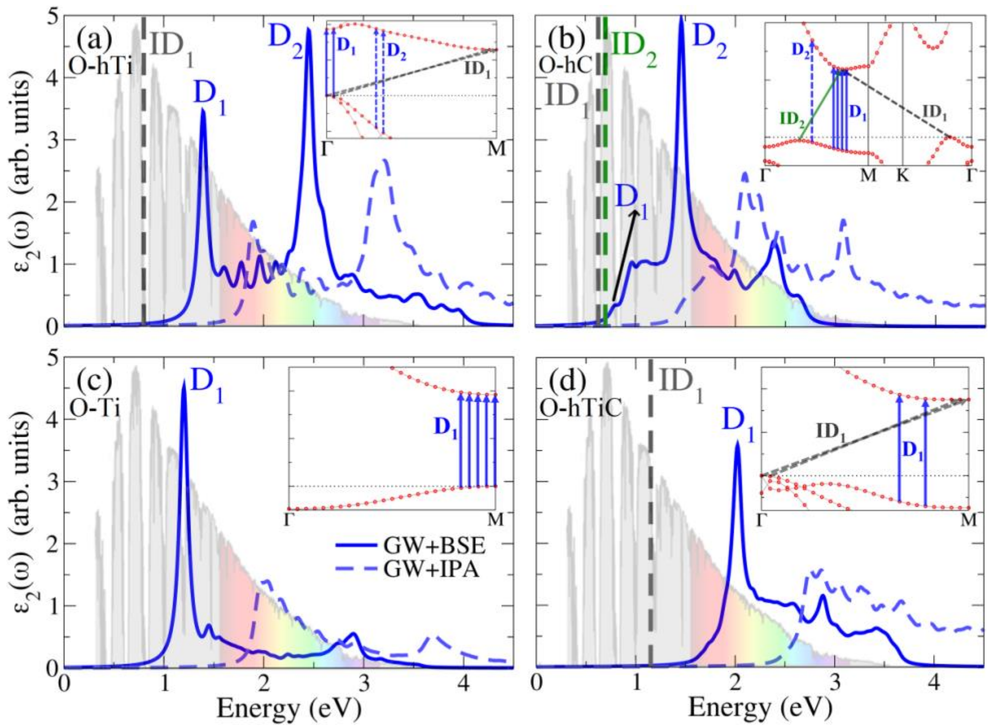

Figure 5: The imaginary part of the dielectric functions—proportional to the absorption spectrum—of the O-terminated Ti2CO2 monolayer models: (a) O-hTi, (b) O-hC, (c) O-Ti, and (d) O-hTiC. See Phys. Rev. Mat. 6, 026001 (2022) for details.

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Optical Properties of semiconductor MXene layers

In collaboration with the team behind the Yambo code (https://www.yambo-code.eu), we have established a framework to incorporate intraband optical transition computations into our initial-principles investigation of metallic architectures. Our findings suggest that factoring in the Drude correction at the GW level (screening level) exerts a notable impact on the behavior of two-dimensional systems. Therefore, its incorporation is essential for a precise and comprehensive assessment of the optical traits of metallic layers.

Superconducting Properties of semiconductor MXene layers: We have conducted a comprehensive analysis using first-principles techniques to identify novel superconductors within monolayer MXenes. We considered all potential combinations of ten transition metal elements from groups 3 to 6 of the periodic table, in conjunction with carbon (C) and nitrogen (N). To evaluate the possibility of superconductivity, we utilized the Eliashberg formalism, combining it with ab initio calculations of electronic and vibrational characteristics, along with the electron-phonon interaction.

Our investigation yielded the discovery of six new monolayer superconductors. Among these, group 6 MXenes, especially those based on molybdenum (Mo) and tungsten (W), demonstrated particularly promising results, exhibiting superconductivity. The critical temperatures (Tc) ranged from 6 K in Mo_2C to 16 K in Mo_2N. Notably, Mo_2N, which possesses a viable synthesis method as demonstrated in this project, emerged as a notable compound.

Furthermore, we identified an additional superconducting compound, Ta_2N, within group 5 MXenes, with a Tc of 2 K, as well as Sc_2C within group 3 MXenes, with a Tc of 4 K.

Interestingly, our exploration revealed the emergence of W_2N as a new material exhibiting charge density wave (CDW) properties. This was based on a commensurate phonon instability indicating a CDW that is twice the lattice parameter. The resultant 2×2 in-plane periodically distorted lattice of W_2N, in combination with a substantial electron-phonon interaction, establishes a rare system beyond transition metal dichalcogenides (TMDs), allowing for the investigation of the interplay between CDW and superconducting states.

Also, analysis of hydrogenated MXenes has revealed consistently improved superconducting properties compared to their pristine counterparts (up to 30 K of Tc). The hydrogenated MXene structures considered here can be realized either by surface functionalization of monolayer samples or by intercalation of multilayer MXene samples with hydrogen. Several mechanisms for the enhanced superconducting properties were identified: enhanced electron-phonon coupling, an increase in the electronic density of states at the Fermi level due to charge transfer from hydrogen to the MXene layer, and the flat segments in the electronic dispersion resulting in a Van Hove singularity in the density of states at around Fermi level.

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As a final investigation, we set out to theoretically identify the effects of selected functionalizations on superconductivity in the otherwise not superconducting Nb2C MXene crystal. Furthermore, we have explored the effects of dimensionality, gating, and applied strain on the superconducting properties of functionalized Nb-carbide MXenes. Our first-principles calculations yielded profound possible improvements in the superconducting transition temperatures, as seen in the following table.

Table 1: Summary of the calculated superconducting transition temperatures of all the considered functionalized MXene compounds

	Material	*tsmear* (Ha)	Strain (%)	Carrier doping (#e/u.c.)	λ	T_c (K)
Bulk	Nb_2CCl_2	0.0075	—	—	0.78	6.3
Bulk	Nb_2CCl_2	0.0075	—	−0.08	1.01	10.5
Bulk	Nb_2CCl_2	0.0075	—	−0.28	1.74	20.7
Bulk	Nb_2CCl_2	0.0075	—	−0.64	4.54	35.4
2D	Nb_2CCl_2	0.0075	—	—	0.89	9.6
2D	Nb_2CCl_2	0.0075	0.25	—	1.01	11.8
2D	Nb_2CCl_2	0.0075	0.50	—	1.29	16.4
2D	Nb_2CCl_2	0.0075	0.75	—	2.14	25.6
2D	Nb_2CCl_2	0.0075	—	−0.06	1.02	11.9
2D	Nb_2CCl_2	0.0075	—	−0.20	6.08	37.8
2D	Nb_2CS_2	0.0015	—	—	0.87	10.7
2D	Nb_2CS_2	0.0015	2.00	—	0.94	11.0
2D	Nb_2CS_2	0.0015	4.00	—	1.84	12.0
2D	$Nb_3C_2S_2$	0.0050	—	—	1.72	28.1

MXene layer for battery applications

The possible use of MXene layers in ion battery applications has been investigated. Our results clearly show that the MXene layers are promissing to be used in future battery technology.

Excitonic Properties of Janus Transition Metal Dichalcogenides

Advanced first-principles investigations focusing on combinations like MoS2@MoSSe, MoS2@MoSeS, MoS2@WSSe, and MoS2@WSeS, reveals that the orientation of the Janus layer's polarization can be effectively utilized to manipulate exciton dynamics. This manipulation includes altering the energy gap between excitonic states in the plane and those between layers, all without the need for external fields.

Remarkably, our calculations for MoS2@WSSe indicate that the energy difference aligns exactly with in-plane optical phonon modes. Furthermore, our calculations of exciton-phonon interactions at zero momentum indicate efficient scattering of excitons between in-plane and interlayer states facilitated by optical phonons. Once again, MoS2@WSSe emerges as a key candidate for this process. Notably, it's worth mentioning that this system also exhibits an indirect band gap. Consequently, the emergence of new, lower-lying dark excitonic states at non-zero momentum could introduce an additional pathway for exciton dynamics. This factor might impact the conversion rate from intralayer to interlayer states.

This presents a promising avenue for future exploration, encompassing theoretical investigations, experimental studies, and materials design considerations.

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PUBLICATIONS

The details can be found in the papers (Table 2) that are attached.

Table 2. papers that have been published as a result of this study

Authors	**Title**	**Journal**	Situation
Z Kandemir, E Torun, K Sendur, C Sevik	Assessment of the potential of MXene crystals as Electron Magnetic Shielding material		Simulations are about to finish
Z Kandemir, E Torun, K Sendur, C Sevik	The electronic and optical properties of the promising metallic MXene monolayers		Under Prep.
C Sevik, J Bekaert, MV Milošević	Superconductivity in functionalized niobium-carbide MXenes	Nanoscale	Published 2023
E. Torun, F. Paleari, M. V. Milosevic, L. Wirtz, C. Sevik	Intrinsic control of interlayer exciton generation rate in van der Waals materials via Janus layers	Nano Letters	Published 2023
Z Kandemir, E Torun, F Paleari, C Yelgel, C Sevik	Surface termination dependence of electronic and optical properties in MXene monolayers	Physical Review Materials	Published 2022
J Bekaert, C Sevik, MV Milosevic	Enhancing superconductivity in MXenes through hydrogenation	Nanoscale	Published2022
C Sevik, J Bekaert, M Petrov and M V Milossevic	High-temperature multigap superconductivity in two-dimensional metal borides	Phys. Rev. B	Published 2022
O. Caylan, G. Buke	Low-temperature synthesis and growth model of thin Mo2C crystals on indium	Scientific Reports	Published 2021
F. Turker, O. Caylan, G. Buke	Nucleation and Growth of Graphene/Mo_2C Heterostructures on Cu through CVD	JACerS	Published 2021
J Bekaert, C Sevik, MV Milosevic	First-principles exploration of superconductivity in MXenes	Nanoscale	Published 2020
E M D Siriwardane, I Demiroglu, C Sevik, F M Peeters, and D Cakır	Assessment of Sulfur-Functionalized MXenes for Li-Ion Battery Applications	The Journal of Physical Chemistry C	Published 2020
U Yorulmaz, I Demiroglu, D Cakir, O Gülseren and C Sevik	A systematical ab-initio review of promising 2D MXene monolayers towards Li-ion battery applications	Journal of Physics: Energy	Published 2020

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CONFERENCES

Table 3. Conferences (C) presentations

Authors	Title	Conference	Talk/Poster
E. Okay, O. R. Caylan, B. Incecik, G. C. Buke	The Synthesis and Characterization of Mo2CTx MXene by Hydrothermal Etching Using Different Fluoride Salts for EMI Shielding Applications	IMMC 2022, Istanbul, Turkiye, October 2022	Talk
O. Caylan, F. Turker, D. Karadeniz, E. Okay, G. Buke	The Effects of Process Parameters on the Synthesis and Characterization of 2D Mo2C Crystals and Graphene Heterostructures Through CVD	NANOTR 16, Ankara, Turkiye, September 2022	Talk
E. Okay, O. Caylan, B. Incecik, G. Buke	The Synthesis and Characterization of Mo2CTx MXene by Hydrothermal Etching Using Different Fluoride Salts for EMI Shielding Applications	NANOTR 16, Ankara, Turkiye, September 2022	Poster
O. Caylan, F. Turker, D. Karadeniz, D. Cakir, T. Turkoglu, G. C. Buke	Synthesis and Characterization of 2D Mo2C Crystals and Graphene Heterostructures Through CVD	MRS, Honolulu, USA, May 2022	Talk
G. C. Buke, O. R. Caylan, O. T. Ogurtani	Growth Mechanism of 2D Mo_2C on Cu *via* CVD	Condensed Matter Physics Meeting, December 2022, Ankara	Invited Talk
Z Kandemir, E Torun, F Paleari, C Yelgel, C Sevik	Electronic, Optic and Excitonic Properties of Functionalized MXene Crystals	Condensed Matter Physics Meeting İzmir, May 2022	Talk
S. A. Sumatya, O. Caylan, G. Buke, M. Baykara	Atomically Resolved Imaging of Electronic Defects of CVD Grown Transition Metal Carbide: α-Mo2	MRS Fall Meeting, Boston, USA, November-December 2021	Talk
C. Sevik, J. Bekaert, M. Milosevic	Superconducting Properties of MXene Monolayers	TOPOSUPER 2021, Helsinki/Finland, June 2021	Poster