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Experimental investigation of the nonlinear properties of NbX₂ Hybrid LTMDs (layered transition metal dichalcogenides) materials in the near-infrared spectral region.

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Nonlinear Photonics in NbX₂ (X=S, Se, Te) based Hybrid Layered Transition Metal
Dichalcogenides (LTMDs)

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The project Nonlinear Photonics in NbX₂ (X=S, Se, Te) based Hybrid Layered Transition Metal Dichalcogenides (LTMDs) aimed at evaluating the nonlinear optical properties of a particular family of Hybrid Layered Transition Metal Dichalcogenides (H-LTMDs), whereby LTMDs were modified with organic/inorganic materials in order to enhance their nonlinear optical response. The two years project followed up NLO characterization of 04 different LTMDs, namely MoS₂, WS₂, NbS₂ and ZrTe₂, started in a former project, which is being extended in the first year for six new LTMDs (MoSe₂, MoTe₂, WSe₂, WTe₂, ZrSe₂ and NbSe₂). The NLO characterization included different spectro-temporal regimes, from femtosecond regime, normally associated with electronic response of the material, to the cw regime, which is associated with thermal response. For the 04 materials initially studied, the reported work in the femtosecond regime was already published (see publication list), whereby the nonlinear refraction and nonlinear absorption response in the femtosecond regimes were studied. Another manuscript reported on the intensity dependent thermally induced nonlinear optical response of the 10 samples of 2D Layered Transition Metal Dichalcogenides in Suspension (Acetonitrile) is under final review in ACS Photonics. The above work was carried out partially in 2020 and mainly in 2021/22. Finally, a manuscript on second order nonlinear effects measured by Hyper Rayleigh scattering was published under the support of the former grant by AFOSR.

In the second year (2022), besides finalizing the thermal nonlinear response work, we studied the femtosecond time resolved nonlinear response of 04 LTMDs and two hybrid systems based on NbS₂, using the Optical Kerr Gate (OKG) method. The results are in final stage of manuscript elaboration for submission to scientific Journals.

Published work

From the end of former grant to Year I of this grant

- 1) *Fifth Order Optical Nonlinear Response of Semiconducting 2D LTMD MoS₂*
Melissa Maldonado, Manoel L. da Silva Neto, Leonardo de S. Menezes, Cid B. de Araújo, Ali M. Jawaid, Robert Busch, Allyson J. Ritter, Richard A. Vaia and Anderson S. L. Gomes, **Opt. Lett.**, **226-229**, **2021**.
- 2) *Femtosecond Nonlinear Refraction of 2D Semi-metallic Redox Exfoliated ZrTe₂*
Melissa Maldonado, Manoel L. da Silva Neto, Pilar G. Vianna, Henrique B. Ribeiro, Cid B. de Araujo, Christiano J. S. de Matos, Leandro Seixas, Ali M. Jawaid, Robert Busch, Allyson J. Ritter, Richard A Vaia and Anderson S. L. Gomes, **App. Phys. Lett.** **118**, **011101 (2021)**;

3) *Femtosecond Nonlinear Optical Properties of 2D Metallic NbS₂ in the Near Infrared*

Melissa Maldonado, Manoel L. da Silva Neto, Pilar G. Vianna, Henrique B. Ribeiro, Vanessa O. Gordo, Isabel C. S. Carvalho, Leonardo de S. Menezes, Cid B. de Araújo, Christiano J. S. de Matos, Leandro Seixas, Ali M. Jawaid, Robert Busch, Allyson J. Ritter, Richard A. Vaia and Anderson S. L. Gomes, **J. Phys. Chem. C** **2020**, **124**, **28**, **15425–15433 (2020)**

4) *Nonlinear Optical Interactions and Relaxation in 2D Layered Transition Metal Dichalcogenides Probed by Optical and Photoacoustic Z-scan Methods*

Melissa E. Maldonado, Avishek Das, Ali M. Jawaid, Allyson J. Ritter, Richard A. Vaia, Danilo A. Nagaoka, Pilar G. Vianna, Leandro Seixas, Christiano J. S. de Matos, Alexander Baev, Paras N. Prasad, and Anderson S. L. Gomes, **ACS Photonics** **2020**, **7**, **12**, **3440-3447**

5) *Hyper-Rayleigh Scattering in 2D Redox Exfoliated Semi-metallic ZrTe₂ Transition Metal Dichalcogenide*

Manoel L. da Silva-Neto, Renato Barbosa-Silva, Cid B. de Araújo, Christiano J. S. de Matos, Ali M. Jawaid, Allyson J. Ritter, Richard A. Vaia and Anderson S. L. Gomes, **Phys. Chem. Chem. Phys.**, **22**, **27845-27849 (2020)**.

Year II of this grant

6) *Second harmonic scattering of redox exfoliated two-dimensional transition metal dichalcogenides*, Melissa Maldonado Cantillo, Anderson M. Amaral, Zacharie Behel, Estelle Salmon, Cid B. de Araújo, Anderson S. L. Gomes, Ali M. Jawaid, Allyson J. Ritter, Richard A. Vaia, Christian Jonin, Pierre-François Brevet, **Optical Materials** **133 (2022) 112780**.

7) *Intensity-dependent thermally induced nonlinear optical response of 2D Layered Transition Metal Dichalcogenides in Suspension*

Jessica E. Q. Bautista, Cecília L. A. V. Campos, Manoel L. da Silva-Neto, Cid B. de Araújo, Ali M. Jawaid, Robert Busch, Richard A. Vaia, and Anderson S. L. Gomes, **ACS Photonics (under final review, Dec 2022)**

8) *Ultrafast near infrared nonlinear optical response of hybrid 2D amine functionalized metallic NbS₂*

Allyson J. A. Carvalho, Denise Valente, Cecília L. A. V. Campos, Ali M. Jawaid, Robert Busch, Richard A. Vaia and Anderson S. L. Gomes, **Manuscript in final preparation stage (Dec 2022)**

9) *Near-infrared ultrafast third-order nonlinear optical response of 2D NbS₂, NbSe₂, ZrTe₂ and MoS₂*

Allyson J. A. Carvalho, Denise Valente, Cecília L. A. V. Campos, Ali M. Jawaid, Robert Busch, Richard A. Vaia, and Anderson S. L. Gomes, **Manuscript in final preparation stage (Dec 2022)**

10) *Spatial self-phase modulation of optical vortex beams in liquid suspensions of 2D materials and organic solvents*

Cecília L. A. V. Campos, Jessica E. Q. Bautista, Anderson M. Amaral, Cid B. de Araujo, Ali M. Jawaid, Richard A. Vaia, and Anderson S. L. Gomes, **Manuscript in final preparation stage (Dec 2022)**

11) *Optical limiting in pristine and hybrid 2D amine functionalized metallic NbS₂ in the nanosecond regime*

Jessica E. Q. Bautista, Cecília L. A. V. Campos, Arthur Cesare, Avishek Das, Ali M. Jawaid, Robert Busch, Richard A. Vaia, and Anderson S. L. Gomes, **Manuscript in initial preparation stage (Dec 2022)**