Electrophoretic Deposition of Nanomaterials For Plasmonically Enhanced Photodetectors

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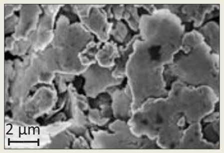
Introduction

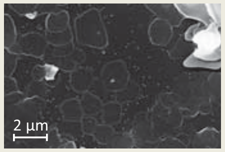
Nanocarbon materials coupled with plasmonically active nanoparticles show great promise in ultrafast, tunable photodetection.[1] However, current methods for producing such devices are costly and non-scalable, making them impractical for manufacturing.[1,2] In this study, we explored electrophoretic deposition (EPD) as a means of simply and inexpensively fabricating structures necessary for plasmonically enhanced photodetectors.

Nanomaterials

- Graphene
  - Grade 4 nanoplatelets: 1-2µm diameter
  - Grade 5 "GraphenX": 20-100nm diameter

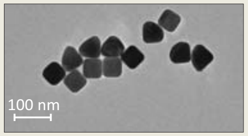


Graphene Nanoplatelets Grade 4



GraphenX

- CTAB Functionalized Au Nanocubes
  - 50nm average diameter
  - CTAB creates ion bi-layer with net positive charge around Au[3]



Au Nanocubes

Electrophoretic Deposition

- Utilized electrophoretic deposition to create Au nanocube and graphene films
- Used two parallel electrodes to create electric field in suspension of Au and graphene
- Coulombic force causes deposition on working electrode
  - OH^- edge groups give graphene net negative charge
  - Ion bi-layer gives Au nanocubes net positive charge[3]

EPD apparatus

- EPD usually used to deposit on conducting substrate[3,4]
- Needed dielectric substrate for our device
  - Si wafer coated with 100nm Al_2O_3
- Achieved deposition using **EPD lithography**

Electrophoretic Deposition Lithography

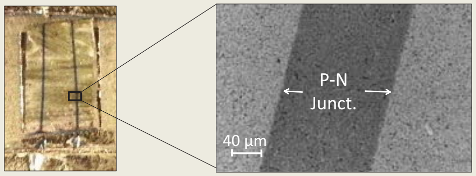
- Employs use of conducting mask
  - Simple wire optimal material
- Mask edges create strong local fields at contacts with Al_2O_3
- Allows for effective deposition at low electric field strengths

Wire mask applied to Al_2O_3/Si wafer

Wafer after deposition
(Au @ 4.6 V/cm for 26 min, GraphenX @ 105 V/cm for 45 min)

Device Fabrication

- Al_2O_3 coated in of Ti/Au (5nm Ti, 50nm Au)
  - Vertical wire masks create gap in coating
- Creates p-n junction needed for current generation[2]
  - Separates electron-hole pairs[2]
- Contacts applied across gap in Ti/Au coat before testing

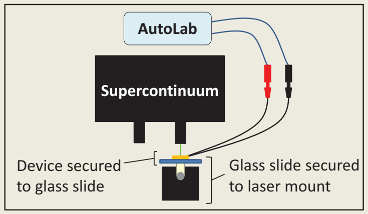


Finished device before contacts applied

Testing Procedure

- Tested for plasmonic enhancement with I-V measurements using AutoLab PGSTAT101
- Used a Supercontinuum Acousto-Optic Tunable Filter as photon source at wavelengths of 450 nm, 550 nm, and 650 nm
- I-V measurements for each wavelength taken at various locations along gap in Ti/Au

Device ready for testing

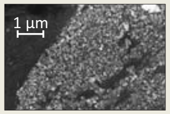


Testing schematic

Results

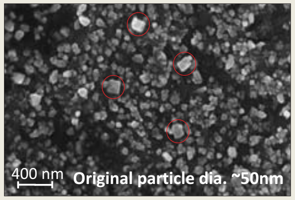
Morphologies and Electrochemical Deposition

- Characterized Au nanocube morphologies using SEM
- Confirms effective deposition with EPD
- Confirms simultaneous electrochemical deposition of Au nanoparticles[3]

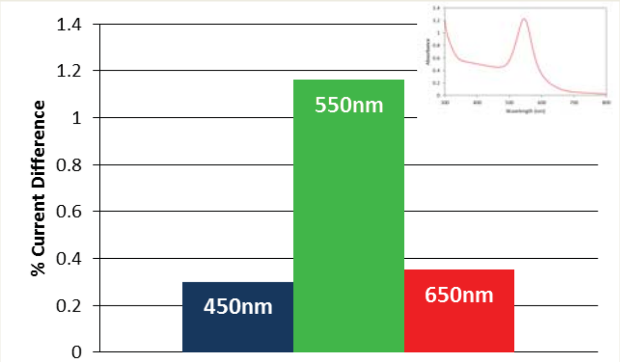


EPD generates areas of dense Au coverage ideal for plasmonic enhancement.

Electrochemical deposition occurs as Au+ ions are reduced to Au atoms on the original Au particles[3]. This results in a broadening of the plasmonic peak and poor plasmonic enhancement.



Plasmonic Enhancement



Inset figure shows absorbance spectrum of the device's Au nanocubes. Its absorbance peak of ~550nm coincides with the greatest observed average % current difference.

Conclusions

- EPD viable means of producing morphologies suited for plasmonic enhancement
- Enhancement hindered by electrochemical deposition and broadening of plasmonic peak
- Future research should aim to reduce electrochemical deposition while still creating tightly packed particle distributions.

Acknowledgments

- Work supported by NSF grant DMR-1005023
- Thank you to Holly Zarick and Olivia Hurd for sythensis and image of CTAB Au nanoparticles

References

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