Optimizing the identification of graphene mono- and bilayers on multi-layered-systems

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Graphene has recently attracted a great deal of interest as material for future nanoelectronic devices due to its excellent electronic transport properties. However, to date most investigations of graphene imply the deposition of graphene flakes on a substrate, necessitating an unambiguous identification of mono- and bilayers with optical microscopy. While it is well known that e.g. a 90 nm SiO_2 [1] or 72 nm Al_2O_3 [2] layer on top of a silicon substrate provides sufficient contrast to observe a monolayer of graphene this fact limits at the same time experiments to be done on a single layer substrate. However, the deposition of graphene on a multi-layer system providing for instance buried gates is desirable as well as the incorporation of alternative materials such as high-k gate dielectrics.

This work presents an investigation and optimization of the identification of graphene mono- and bilayers on various multi-layer substrates. Instead of the mere contrast between substrate and substrate/mono/bilayer systems [1], the luminance differences are used to obtain optimum visibility, based on the work presented in Ref. [2]. Our approach uses a genetic algorithm is employed that not only allows optimizing the visibility of graphene on a single layer substrate but also enables finding the most appropriate composition of a multi-layer systems in terms of materials in use and their thicknesses. In addition, a major benefit of our approach is the possibility to qualify appropriate layer systems with respect to their manufacturability.

The reflection spectra of a multi-layer system with and without graphene layer are computed using the Fresnel-equations and a transfer matrix formalism [3] as illustrated in Fig. 1. From these spectra colors can be extracted using the CIE-Lab color space [4] which includes the color perception of the human eye. Eventually, three so called color-luminance-difference values (CLD) are obtained where CLD_1 describes the luminance difference between the colors of a monolayer graphene and the top of the multi-layer system, CLD_2 between a mono- and a bilayer graphene and CLD_3 describes the luminance difference between a bilayer and the multi-layer system's surface. A genetic algorithm is then used to optimize the multi-layer system with respect to obtaining maximum differences between the three CLD-values, i.e. obtaining the best visibility and possibility to distinguish between graphene mono- and bi-layers.

Fig. 2 presents a number of multi-layer systems generated automatically with the genetic algorithm. Obviously, which allow a clear colored identification of graphene. The calculated colors for substrate/mono/bilayer graphene are illustrated in row calculated colors. The substrate's color surrounds the monolayer (top) and the one of the bilayer (bottom). All presented systems provide a rather large tolerance in terms of the visibility of grapheme even with thickness variations of each layer of up to +/- 10 nm. Fig. 3 illustrates the visibility of graphene for the multi-layer system 10 (cf. Fig. 2) as a function of the thickness of the three respective layers. All three layer can even vary more then +/- 10 nm, while graphene will still be visibile with optical microscopy.

In summary, by using a genetic algorithm to generate multi-layered-systems, it is possible to achieve an arbitrary multi-layered-system, allowing a clear visibility and identification of mono- and a bilayer of graphene including a large tolerance of layer thickness variations during manufacturing.

References

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Figures

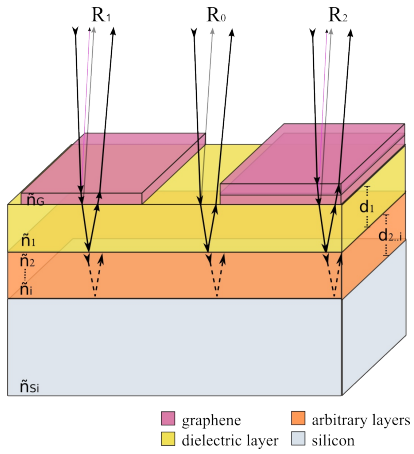

Fig. 1. Fresnel-law-based multi-layered system to achieve the reflection spectra R_0, R_1 and R_2, which are functions of the layer's thicknesses $d_1,d_2...d_n$ and of the refractive indexes $\tilde{n}_1,\tilde{n}_2....\tilde{n}_n$.

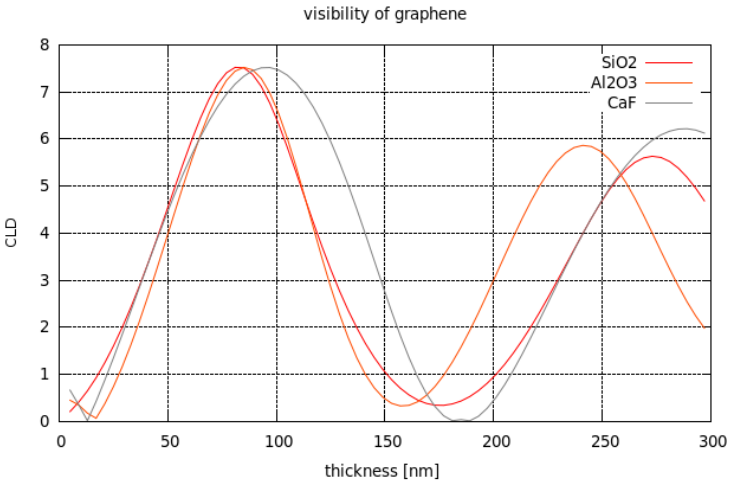

Fig. 3. Visibility of graphene depending on the three layers's thicknesses for stack 10 in Fig. 2.

substance	stack1	stack2	stack3	stack4	stack5	stack6	stack7	stack8	stack9	stack10	stack11	stack12
Graphene												
SiO_2	300 nm	90 nm				65 nm	61 nm	37 nm		81 nm	83 nm	85 nm
Al_2O_3				72 nm			25 nm			85 nm	221 nm	131 nm
Si_3N_4			55 nm									
HfO_2						25 nm			45 nm		25 nm	10 nm
CaF					90 nm			242 nm		95 nm		
Ag									20 nm			20 nm
Si												
Calculated colors:												
CLD1	1.2	2.2	0.5	1.8	2.3	2.1	2.2	2.2	2.3	1.9	2.1	1.4
CLD2	1.1	2.2	0.4	1.8	2.2	2.1	2.2	2.2	2.3	1.9	2	1.4
CLD3	2.2	4.4	1	3.6	4.5	4.3	4.3	4.5	4.6	3.8	4.1	2.8
Σ CLD	**4.5**	**8.8**	**1.9**	**7.2**	**9**	**8.5**	**8.7**	**8.9**	**9.2**	**7.6**	**8.2**	**5.6**

Fig. 2. Multi-layered-systems generated using a genetic algorithm, which offer a clear visibility and identification of graphene and at least +/- 10 nm fault-tolerance by layer-manufacturings (cf Fig. 3).