1. An experiment is performed on a process that manufactures integrated circuits. A basic step in the
process is to deposit a thin film (epitaxial layer) on a polished silicon wafer. The wafers are placed in
a chemical vapor deposition (CVD) reactor. Chemical vapors are introduced and the reaction takes
place until the epitaxial layer is the desired thickness. An experiment is run with two factors: vapor
flow rate and time in the reactor. For the purpose of the experiment, one reactor is used and one wafer
is placed in the reactor at a time. Each wafer’s thickness is measured before and after being placed in
the reactor and the thickness (μm) of the epitaxial layer is determined. The same operator processes
and measures all wafers for the experiment. Four wafers are run for each combination of flow rate
and time. The order of the 16 runs is completely randomized. Below are the resulting epitaxial layer
thicknesses (μm).

<table>
<thead>
<tr>
<th>Flow Rate</th>
<th>Time</th>
<th>Epitaxial Layer Thickness (μm)</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>15</td>
<td>14.01 14.13 13.94 13.88</td>
<td>13.99</td>
<td>0.0115</td>
</tr>
<tr>
<td>59</td>
<td>15</td>
<td>13.88 13.79 14.06 13.91</td>
<td>13.91</td>
<td>0.0126</td>
</tr>
<tr>
<td>55</td>
<td>30</td>
<td>14.81 14.76 14.64 14.87</td>
<td>14.77</td>
<td>0.0095</td>
</tr>
</tbody>
</table>

(a) Is this a well designed experiment? Comment briefly on control of outside variables, randomization
and replication within the experiment.

(b) Calculate means for each level of flow rate and each level of time.

(c) Display the means for flow rate and time and comment on the apparent effects of each factor.

(d) Construct two interaction plots, one with flow rate on the horizontal axis, one with time. Does
there appear to be an interaction between the two factors? Explain briefly.

(e) Compute the $MS_{repError}$ by pooling the individual sample variances for each treatment combi-
nation.

(f) Calculate the estimated full effect for each factor and the interaction effect.

(g) Give the standard error of an estimated full effect and use it to determine what estimated effects
are statistically significant. Use $t=3$ for the critical value.

(h) Eliminate any nonsignificant effects and give the reduced model prediction equation. Be sure to
define the coded predictors explicitly.

(i) Predict the values for the four treatment combinations. Construct prediction intervals for each of
these values.

(j) What recommendation would you make if you wanted an epitaxial thickness of 14.2 μm?

(k) We could also look at this experiment as a “one-factor” experiment, where the “treatments” for
the “one-factor” are combinations of flow rate and time. Calculate the LSD (use $t=3$) for such
an experiment.

(l) Based on the LSD, which “treatments” are significantly different? not significantly different?
Does this analysis agree or disagree with the one done previously? Explain briefly.

Note: You may use JMP, or another computer program, to assist you with any of the graphing or calculations
needed to answer the questions above. However, since exams will contain some hand calculations it may be
worthwhile to do the calculations by hand and verify the hand calculations with the computer.